Mineral Development in Ontario North of 50°

Technical Paper #11

Radioactive Fuel Minerals

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the ROYAL COMMISSION on the NORTHERN ENVIRONMENT

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RADIOACTIVE FUEL MINERALS URANIUM (AND THORIUM)

INTRODUCTION

After 22 months of intense and total involvement in the preparation of these reports on the outlook of mineral markets over the next 25 years it became clear that the report left for the end - on radioactive fuel minerals - was not the proverbial 'cinchy piece-of-cake' as one might have assumed at the beginning. On the contrary, this investigation of the nuclear mineral field developed into a very much more complex analysis and required more research than initially anticipated. Certain issues of great currency had to be side-stepped in order to avoid touching upon a 'tin of radioactive worms' or to be lost in the jungle of issues of the 'global nuclear tinderbox', to continue in the same proverbial vein of speech. However, the writer was well aware of the dilemma that the environmental problem of so immense a scope was germaine to the subject of nuclear fuels but physical too large to be studies in depth and really outside the explicit terms of reference of the contract. At the same time, it had also been clear that this entire complex problem would influence at least the uranium market.

To a very small degree the impact of public concern over the nuclear issue has been included. But this inclusion understandably will not meet with the approval of the general public, because it is insufficiently treated and because it

relates well-intended public concern to the field of generation of cheap electrical energy and to the cost and availability of nuclear fuels and not to the key environmental issues. The writer therefore regrets at the very outset and apologizes that it has been impossible for him to do justice to the real public (environmental) costs of the entire global nuclear complex of problems. Obviously, that real cost problem has several key areas which are briefly summarized in the following way.

Generation of Nuclear Energy

Two problems seem to stand out as the main issues: the control of radioactive waste and the risk of proliferation of substances potentially useful in making nuclear, destructive devices especially by unauthorized people.

The first of these difficulties would have to be solved by nuclear scientists and engineers. It would mean that by the year 2004 a summary lethal pile of nuclear radioactive waste with a half-life of 25,000 years and measuring in compacted form 75 x 75 x 10 metres - or one million metric tons - of burnt uranium for the entire western world would have to be fail-safely handled,processed,shipped and stored; this waste quantity would result if all uranium expected to be mined between 1980 and 2004 would also be consumed.

The problem of proliferation appears less amenable to a straight forward solution because the probability co-efficient of that risk increases with the volume of the waste produced and with the geographical dispersion of a rising number of nuclear reactors.

Reactor Accidents

Reactor accidents could occur with varying degrees of severity ranging from light to grave consequences. The Three Mile Island affair was one of the lighter consequences while a core melt-down or even an atomic explosion of a reactor certainly would come under the class of grave consequences. Naturally, again the risks do increase with the number of such reactors and it is also obvious that any malfunction ultimately can only be explained on the grounds of human error.

Nuclear Weaponry

Men have never failed to incorporate means of mass destructive powers into their military arsenals. The writer is not qualified to discuss these issues in detail because he is not militarily involved. But it has to be admitted that this type of nuclear ever-presence imposes a definite cost on each and every citizen on this earth though the magnitude of these costs may differ according to the nervous

sensitivity and daily awareness of those dangers among individuals. The ultimate prospect of a military nuclear exchange defy any description and the results of such a possibility are infinitely large real public costs: total and absolute destruction, the absolutism of economic costs!

This problem penetrates the arteries and nerves of the whole country, of any country, that is. The risk of nuclear destruction today carries with it a global atomic potential of more than a million times of the Hiroshima device which had an explosive power of 20,000 tons of TNT. This is general knowledge and has been dramatized by Nevil Shute's On the Beach. In short, it is clear that we can now be killed about ten-times over in such a nuclear convulsion! Therefore, a different type of conflict is being taken into consideration: the 'limited' nuclear exchange! It is supposedly of greater public palatability since it does not mean deployment of all strategic nukes in the world and remains confined to a special geographic area!

Combination Effects

The worst scenerio was recently painted in the Scientific American.[0] This picture is so serious in its possible implications that it has to be pointed out here. The gravest of all dangers is a nuclear exchange with hits of nuclear reactors in enemy countries. Destruction would be most com-

plete. At that point, one might argue that the dialectic process would have come to an end. The event itself is a military impossibility along the Moltke-Clausewitz tradition which works of the base of a 'Kriegsziel' - purpose of war. And such a war aim cannot be self-destructive on any part of the combattants. All-out nuclear war is a military non-sequitur but possible on grounds of political-ideological schizophrenia or due to hysteria with DT at the red button.

In short, it would be a complete surprise were people found to be unsusceptible to the extreme fears of such terrible prospects. But apparently, part of the game strategies is to exploit this angle to the advantage of one side or the other or both. Whether nuclear weaponry should be abolished by international agreement does not solve all the issues at the roots of conflicts. Today, there are other weapon prospects with almost comparable intensity of destructiveness as nuclear arms. Such weapons as have been or are being produced for use against one's potential enemies include means of bacteriological and chemical warfare to which laser and particle beam weaponry will be added.

Lest it be forgotten that atomic weapons ended the Second World War. It is also true that the abolition of such military hardware may take the worst fears out of men's minds but may likewise indirectly reopen the world stage

for a repeat war performance with more conventional tools.

What, then, was this study about? It was to show that:

1. until at least the end of this centruy there is no purpose in sinking more capital into new uranium ventures in this province;
2. by the end of the forecast period about half of the short-run reserves known at a price of up to $US 30/lb of U_3O_8 may have been exploited;
3. prices cannot be maintained above that level for long, at least in the short-run;
4. the price hike of the past was a costly exercise for the public at large and a) a result of a transitional instability stemming from decreased military application with commercial consumption still insufficient to counteract that decline, and b) it was accommodated by oligopolistic market interference from a cooperative effort by select corporations and most senior governments;
5. higher prices produced greater and more certain reserves such that
6. end-users may cut down on inventories due to a more certain fuel availability than before.

It can also be demonstrated that in the long run, if one can see that far ahead,

7. new uranium ventures will unlikely be profitable before

the beginning of the next century unless the exploitation of newly discovered high-grade uranium deposits can be phased in;

8. Canada will be one of the few strong and lasting suppliers of uranium at home and abroad due to its huge long-run reserves;

9. Nuclear technological change will negatively affect uranium prices and the uranium mining industry but extend the time horizon of resource availability;

10. Canada missed an early chance to adopt breeder technology to supply its economy early with cheaper energy while it must also be realized that

11. inflation, in as much as it is energy related, is equivalent to holding the knife to the throat of the 'golden goose' - i.e. the Canadian mining industry and that advanced fuel cycle technology could combat the crippling disease;

12. future consumption and demand for mined uranium will be determined a) by the number of uranium reactors and b) it will be modified by the degree of breeder reactors in the world system which might lead to lower prices of uranium and of energy than without breeders;

13. nuclear mineral resources availability would stretch over centuries;

14. the failure to implement advanced fuel cycle technologies

including the thorium cycle due to public resistance and other institutional rigidities world uranium resources including speculative resources will deplete more quickly than otherwise would be the case leading to higher uranium prices while the uranium mining industry will become very active at the expense of a shorter life expectancy;

15. such price developments should trigger the substitution of uranium by the much more energy-efficient thorium which should also then produce cheaper electricity;

16. the date for this event most likely will be determined by the constellation of the uranium industry which may become also the supplier of thorium.

It can generally be concluded that:

17. in essence, there cannot be any shortage of nuclear fuel minerals and any actual shortages in fuel supplies are temporary and created by imperfections in this strongly institutionalized market complex;

18. a repeat performance of a uranium cartel cannot be discarded off hand but that the likelihood of such an event will be more remote because many countries are keenly interested in developing their own potential uranium resources.

The study is organized in the following manner: Section I introduces the reader to the most important aspects of nuclear

physics as concerns the concepts of fission, neutrons, uranium, thorium and plutonium fuels and the reactors. Section II is a brief exposition of the difficulties encountered in retrieving world-wide uranium consumption statistics, while Section III explores uranium mining production of the world, Canada and for the Province of Ontario between the years 1956 and 1979. This section deals also with the significance of the main uranium producing countries in the world as well as with the Canadian uranium trade and its extreme external vulnerability. In the course of this investigation some basic information on an international and, partially, government-sponsored marked arrangement - called the cartel - will be presented to be concluded by a brief report on recent developments in the exports of radioactive ores and concentrates. Uranium reserves and resources and their distribution among the main countries in the Western World are at first scrutinized in Section IV followed by an examination of uranium investment activities and other contemporary nuclear aspects of the main alternative suppliers including Canada as well. Highlights in the field of uranium mining in other countries have been reserved for footnote 152. The performance of uranium prices, past, present and future and the future of uranium production, consumption and maximum mining capacities are analysed in Section V with summary and conclusions to follow.

SECTION I: NUCLEAR FUEL MINERALS: URANIUM AND THORIUM

Background Information

In the year 1920 there was no demand for a metal called uranium. It had been hidden in the past as something nobody looked for and, therefore, an economic scarcity did not exist! There may have been a natural scarcity of the metal for those scientists who made it the centre of their academic pursuits. As a geologist remarked facetiously that 'anything is scarce, until someome is looking for it', and that,in essence, was and still is the case for both uranium and thorium.

This brings us to the names. There is thorium: as a matter of fact few people of everyday life know of the existence of this metal. They may be aware that there was god Thor in Nordic mythology but they will hardly be cognizant that he 'had' his own metal, at least in name and a nuclear one for that!

If a nuclear metal is well-known today, then it is, no doubt, uranium. This name is to be traced back to the planet uranus[1] but it was long before the discovery of this heavenly body that a forefather of Mighty Zeus in Greek mythology bore this name.

The metal thorium was discovered by Berzilius in 1828, while uranium had been noticed as an unfamiliar element in pitchblende by Klaproth in 1789. Although he tried to isolate the metal it was up to Peligot to do so in 1841.[2]

These metals would have remained unimportant in the eyes of mankind in general had not certain developments in science taken place which changed the course of history. This chapter of the history of the Atomic Age was opened by events of cataclysmic proportions: atomic bombs!

Without attempting a rerun of the history of nuclear physics, some points need be recalled to relate this part of the natural sciences to the economic side of development through what is called 'technological change'.

For long, scientists had tried to explore the microcosmos of matter: the structure of the atom. But it was only in 1920 that Ernest Rutherford in his Bakerian Lecture[3] postulated the existence of an electrically neutral particle: the neutron. This tiny particle was, indeed, discovered in 1933 by James Chadwick as the field of nuclear science expanded dramatically in Europe and North America. Names of other physicists besides Rutherford surrounded with aura of greatness in the field were Niels Bohr, the teacher of Oppenheimer, Fermi and Heisenberg at the University of Gottingen in Germany. In 1938, Otto Hahn and Fritz Strassman were successful in smashing atoms in laboratories by bombarding uranium with neutrons. Finally, Albert Einstein should not be forgotten in this brief recall of nuclear celebrities. He was not only a scientist of world stature but also a man of vision. It was in August 1939 that he wrote the now famous letter to the President of the United

States, F.D. Roosevelt, in which he pointed to the great potentialities of atomic fission, its chain reaction and the possibilities of constructing extremely powerful bombs.[4]

Almost one year after the bombing of Pearl Harbour, which had brought the United States into the Second World, the first self-contained chain reaction took place in a squash court under the West Stands of Stagg Field in Chicago on December 2nd 1942. Subsequently, the Manhattan Project was authorized by President Roosevelt leading to the construction of the new city of Oak Ridge which began already on November 22, 1942. In addition, a top-security institute had been established at Los Alamos, New Mexico for designing and constructing of the first A-bombs. With the successful test of the first nuclear device at Alamagordo on July 15, 1945, the atomic era had begun and on August 6, 1945 a uranium bomb destroyed Hiroshima while three days later, on August 9, 1945, Nagasaki met its disaster through a plutonium bomb.

With the end of the Second World War, efforts were concentrated in the United States at first towards the assembly of a considerable arsenal of strategic weapons. The introduction of tactical nuclear weaponry followed on the one side, while the atom was also being utilized for more peaceful purposes in the form of large-scale generation of electricity and also, though to a much smaller extent, through research and development of nuclear medicine by utilizing radioactive

isotopes on the other.

Without entering into the truly scientific details of nuclear physics and fission, some of the important nuclear properties of elements should briefly be studied. These details are essential for the final understanding of the nature and the forces determining future demand and supplies of those metals useful in the generation of electrical energy: uranium and thorium.

The smallest part of an element is its atom and it is the various particles and their number contained in each atom which make it the element it is. These particles are mainly electrons, protons and neutrons. Whereas the former two have electric capacities of mutual attraction - the protons with the positive charge sit in the centre while the negatively attracted charged electrons circulate around the nucleus - the neutrons which Rutherford had envisaged have none.Yet, the neutrons are part of the nucleus, the epicentre of matter.

In short, when a neutron collides with an atom with fissile characteristics the nucleus disintegrates: it splits. In the process, electrons, heat, radiation of specific particles and neutrons are released. But it was also a neutron that led to the splitting of the atom in the first place. Thus through the fission - or splitting - new neutron are emitted which can now collide with other atoms of the same element and cause them to split.

If a large number of neutrons were to be released in each collision the cumulative effect of this geometric progression of nuclear fissions would be an atomic explosion. However, this happens only under specific circumstances. Normally, released neutrons are too fast to penetrate into the nucleus of a fissile element. Instead they will be absorbed by other elements. The probability of causing another fission requires that the neutrons must slow down to hit the fissionable material, or that the quantity of fissionable material present in the material be significantly enlarged.

The problem is to moderate the speed of the emitted neutrons. Scientists came to recognize that elements with light atoms function well in this capacity. Three substances were suitable for that purpose: ordinary water, pure graphite and deuterium oxide. The last of the three substances is generally called heavy water and is also found in ordinary water at a ratio of 1 part of deuterium to 10,000 parts of water. However, it may be produced by enriching the deuterium content of water in heavy water plants.

Instead of using graphite or deuterium as moderators, another way of increasing the probability of fission is to use water and to enlarge the quantity of fissionable material in the main substance. In order to understand the basic composition of the material used in nuclear reactors, it is critical to differentiate between three types of elements contained in

nuclear material. The three types are: fissile or fissionable substances, fertile material and parasitic elements.

Nuclear Properties

Fissile (Fissionable) Substances

There are only three fissile elements:

U r a n i u m 2 3 3,

U r a n i u m 2 3 5 and

P l u t o n i u m 2 3 9.

Of these three elements only uranium 235 may be found in nature in relatively small quantities together with uranium 238 which which cannot be split. The fissile uranium 235, in nature, amounts to 0.7110 of one percent while uranium 238 accounts for 99.2830 percent and uranium 234 for 0.0054 of one percent. Consequently, only a very small percent of U 235 occurs in natural uranium. In order to sustain a chain reaction in certain reactors, the density of uranium 235 has to be increased which is done by special enrichment processes.[5]

The other two fissile elements do not exist in nature and have to be created. This leads to a discussion of the aspect of nuclear fertility.

Nuclear Fertility

Elements are nuclearly fertile if they absorb neutrons emitted through nuclear fission and thereby turn into a new element. One of these fertile elements is thorium 232, an

atom which by addition of a neutron is changed into fissile U 233[6]; the other is uranium 238 which becomes fissile plutonium 239. Of course, this creation of new elements does not stop here. Other elements are created through neutron bombardments but they are unimportant as the generation of electricity is concerned.

Parasitic Elements

A third possible consequence of fission besides new fission and the creation of new elements is that emitted neutrons are absorbed by certain elements without any reaction. These neutrons are lost and go to waste and that is why such neutron-absorbing substances exercise a parasitic function. They reduce the chain reaction potential whenever present and, at worst, may frustrate any start-up or abort any on-going chain reaction if allowed to interfere in the fission process.

Other Aspects of Nuclear Fission

Nuclear physics has come to the conclusion that normally about 2.5 neutrons are released with the splitting of an atom and that about one successful 'hit' by one neutron onto another atom is sufficient and satisfactory for maintaining the chain reaction. Increasing rates of success may trigger a cumulative effect while anything less than one will stop the process altogether. Therefore, a situation in which emitted neutrons create a sustained chain reaction is called the 'critical point'. Above it, fission is maintained and controlled;

below it, the chain reaction ceases and the reactor shuts off.

Conventional (Converter) vs Advanced Fuel Cycles

Following this rudimentary observation of properties of nuclear materials the discussion can now center on the possible fuel cycles and on types of reactors utilized for the generation of energy.

The normal cycle which converts nuclear energy - the heat released in the fission process - into electrical energy uses up the existing uranium 235. Three general types of reactors may be recognized according to the kind of moderator agents used:

1. The graphic reactor (Fermi),
2. The light water reactor and
3. The deuterium oxide reactor (heavy water).

The first of the big reactors ever to start operations outside laboratories was the graphite reactor in the famous X-10 complex of Oak Ridge. It had been modelled after Fermi's Stagg Field reactor, the very first of all reactors using graphite to control the chain reaction.

The second type works with ordinary water, the least satisfactory of the three moderating agents. For this reason, a higher concentration of U 235 is required than occurs naturally. Consequently uranium has to be enriched. This is accomplished by removing some of the very plentiful uranium 238

from the natural uranium through various complex processes.

During fission more neutrons are released than are necessary for a continuous chain reaction of uranium 235. This excess of neutrons hit upon the material most present in the fuel and that is uranium 238 thereby transforming these atoms into plutonium; and that is another fissile, though very poisonous, substance. It can be used as fuel in other reactors - or - in atomic weapons! Therefore, the reactor with ordinary water for a moderator is called the light water reactor and it is still the standard reactor in the United States.

Its advantage is a greater efficiency because it releases more heat than other conventional reactor types and, thus, produces more electricity. Its drawback, obviously, is that natural water streams have been used for cooling purposes leading to thermal pollution of the environment. In addition, it requires substantial amounts of electricity for enriching uranium 235. Take, for instance, the famous K-25 plants and the surrounding installation where the separation and enrichment of U 235 takes place. This complex, which stands on 600 acres and employs 4,000 people consumed "four billion kilowatt-hours of TVA electricity annually" in the 1970s.[7]

The third of the conventional fuel-cycles works with heavy water for a moderator. Although this method does not produce the same heat and electricity as the light water reactor, it does not need enriched uranium as fuel; it runs on natural

uranium! The proto-type for the Western World is the CANada Deuterium Uranium - CANDU - reactor. It is a system which, according to one of the scientists of the Chalk River Nuclear Laboratories, "has consistently outperformed other comparable nuclear power systems in the Western World and has an outstanding record of reliability, safety and economy."[8] That is why the HWR - heavy water reactor - competes favourably with other conventional, once-through, fuel cycles. It consumes the existing one percent of fuel U 235 contained in natural uranium which has not gone through the enrichment procedure.

The one property common to these three reactor types of the conventional variety is that the unburnt uranium 238 becomes a waste product which is then stored in special locations under strict safety provisions. Yet, this used fuel material contains considerable quantities of fissile material which has been generated in the process and which could be recovered and recycled with fresh uranium thereby doubling the power obtainable from a given amount of nuclear fuel.[9] Without such recycling operations these conventional reactors make uranium a depletable resource!

Advanced Fuel Cycles

The advanced fuel cycles differ from the conventional - once through - processes in that they use not only uranium 235 as fuel but rely on uranium 233 and plutonium 239 as fissile materials.

These two fissile substances are created by absorption of neutrons released during the fission of uranium 235 and are not utilized during the chain reaction. Some of the fast neutrons not lost to parasitic elements may strike upon fertile material such as thorium 232 and uranium 238;[10] the former is transformed into U 233 and the latter into plutonium 239, both of which are fissile fuel material. This means that while the reactor is burning it 'breeds' more fuel than it consumed. And according to the substances used, there are two basic types of nuclear breeder cycles; the uranium breeder cycle and the thorium breeder cycle.[11]

Consequently, each cycle produces additional fuel and there is a time when enough fissile substances have been produced to refuel the reactor and to charge an identical additional reactor. The time it takes to generate this fuel is called the 'doubling time'.

The uranium (- plutonium) cycle has a doubling time of between seven and ten years utilizing fast neutrons efficiently. That is why the reactor working on this method is the fast breeder as fast neutrons are less likely to be absorbed by parasitic substances.[11] In turn, the thorium cycle reactor works with slow moving neutrons and has a doubling time of about 20 years. It is a slow breeder cycle - the thermal breeder. A further advantage is that fission efficiency is greater for U 233 than is the case for U 235.[12]

Besides these basic advanced fuel cycles and reactors, there are mixed advanced breeder cycles feeding on thorium, uranium and plutonium in various combinations. All serve the same purpose: they expand dramatically the availability of fuel.[13]

The cooling methods of a uranium - cycle fast breeder differ from those required by the thorium-cycle. The former cool by inert gases such as helium, or by liquid metals, like sodium or by steam. The latter controls the temperatures by light or heavy water or by molten salts.[14]

Breeder Reactors in the World (Global)

The movement towards the exploitation of breeder technology by major industrial countries has been well underway for some time. Already in the late 1950s experimental breeder reactors were built. In 1959, the BR-5 reactor went into operation in the U.S.S.R. Its thermal capacity was 5 MW(th) and 0 W(e). The same year saw the DFR breeder come on stream in the United Kingdom, with 60 MW(th) and 15 MW(e). The United States built three breeders in the 1960s; two of these-EBR II (Experimental Breeder Reactor II) and the large Fermi reactors-were running in 1963, while SEFOR, a small test reactor, was completed in 1969. In Europe, France started with the 'Rapsodie' reactor (for 'rapid sodium').[15,16.]

Starting with 1970 the U.S.S.R. had BOR-60 producing

energy at a capacity of 60 MW(th) and 42 MW(e). Two years later the same country ushered in its first larger breeder BN 350 delivering a capacity of 1,000 MW(th) and 150 MW(e). An even larger one was to follow in 1976, the BN 600 (1,500 MW(th) and 500 MW(e)). The United Kingdom and the United States added each one medium-sized breeder to that list in the year 1973, while France began working on the Phénix project.[17] At this point in time, Germany, Japan and Italy entered the fast breeder scene. Even India had a fast breeder under construction.

A decision of great importance was taken in the fall of 1970 by a consortium of European utility companies to construct a 1,200 MW breeder reactor at Creys-Malville in France. With the name of Superphenix it represented the crown of succœss on the breeder program started with the 'rapsodie'. Planned to produce energy at full scale by 1980 this accomplishment is an expression of the progress which breeders have made in the industrial world. Still, this was not the end. The French national utility company Electricité de France (EDF) called 'for a series of breeder plants, employing plutonium as fuel provided by a large number of pressurized water - reactors built simultaneously.'[18] By the year 2000, fast breeders are expected to represent one quarter of installed reactor capacity and one third of French nuclear energy production.[19]

To this multinational project - Superphénix - has to be added a second in progress in Western Germany, viz. the S.N.R. 2[20] Both will promote the joint effort by European countries to launch commercially viable breeder reactors without which their economies would face great difficulties in the availability of cheap energy!

Developments in the United States have been somewhat different. Former President Carter and his administration have actually cut back on the fast breeder programme for a number of reasons. These breeders use sodium for a coolant which is highly explosive. In addition, the product plutonium is very toxic and poses, understandably, huge problems regarding nuclear waste management. Last, but not least, the rising quantity of plutonium bred by these reactors would raise the risk considerably that such substances, with which almost a high school student could manufacture an A-bomb, would fall into illicit, terrorist hands.

Whatever the likelyhood for such events, the point is well taken especially if there is an alternative solution which was chosen: a light water reactor working on the thorium cycle utilizing an existing light water reactor. This happened in Shippingsport, Pennsylvania late in the 1970s when an ordinary light water reactor was <u>transformed into a thorium cycle light water slow breeder reactor</u>.[21] Spiked with 1,100 pounds of U 233 for ignition in mixture with 40 tons of thorium

the start-up of this reactor marked a turning point into the direction leading away from recognized hazards of the fast breeders towards a safer nuclear management.

The Shippingport reactor is, of course, not the first to use thorium in the United States. Since 1966 the Philadelphia Electric Corporation had an experimental gas-cooled 40 MW power reactor installed in the Peach Bottom Atomic Power Station. It served as a prototype for a 330 MW plant built at Platteville, Colorado by the Public Service Corporation of Colorado.[22]

The country which has gone unmentioned so far in this survey of development of breeder reactors is Canada. Understandably, the ordinary CANDU reactor is an achievement of Canadian expertise in science and engineering technology and the deserved pride of the whole country. Still, Canada is far from exploiting its nuclear potential to the fullest unless steps are taken which eventually will set this country on course to the generation of electricity through breeder reactors. It will, of course, be difficult to overcome the head start which other countries have secured for themselves. To have a commercially viable breeder reactor - made in Canada - will take about 20 years. The general impression conveyed by the various publications of Atomic Energy of Canada Limited is that Canada cannot be expected to make effective use of advanced fuel cycles before the turn of the

century.[23] This does not imply a lack of scientific and engineering know-how on the part of Canada's nuclear physicists and engineers. On the contrary, they are well endowed with the technology necessary to build breeder systems. This is especially true considering that they will follow their own tradition as regards efficiency, health and safety which they established with the CANDU reactor. As a matter of fact, the design of the CANDU unit is adaptable for a breeder cycle, especially of the slow variety.

Not only would such a move relieve the pressure on the allegedly scarce uranium resources of the country and of the world, but it could help initiate a reduction in the cost of electricity. The fact is that electricity generated by the ordinary CANDU system is already much cheaper than that produced by the coal-fired thermal stations.[24] Breeders would also mitigate the energy consumption pressure on fossil fuels while, at the same time, the demand for energy is likely to grow.[25]

It was the former Senior Vice-President (Sciences) of Atomic Energy of Canada, Dr. W. Bennett Lewis, Distinguished Professor of Science at Queen's University who so eloquently pleaded the case for the CANDU-OC-THORIUM reactor on the grounds of its superb economic prospects.[26] In a cost comparison for generating electricity at Pickering and at such a CANDU-OC-THORIUM reactor, the Pickering unit of energy officially costs

3.6 m (1949) \$/kWh[27] whereas energy from a hypothetical thorium reactor would run as low as 1.45 m (1949) \$/kWh, which is about half that cost. The case for putting a thorium reactor into service becomes even stronger if the general availability of thorium is seen in comparison to that of uranium.

Occurrence of Uranium and Thorium

Considering the possibilities offered by the utilization of these two fuel cycles it would seem important to comparatively examine the geological availability of the two feedstocks: thorium and uranium. The surprise awaiting the reader is that thorium and not uranium is the geologically more abundant of the two minerals. This has been brought out in the following breakdown:

Average Abundance of Thorium and Uranium
in the Earth's Crust, in three Common Rocks
and in Seawater (in ppm)[28]

Element	Crust	Granite	Basalt	Shale	Seawater
Th	8.5	20	1.5	12	1×10^{-5}
U	2.7	5	0.5	3.5	0.0032

See also note 29.

Except in seawater, the relative abundance of thorium is three to four times greater than that of uranium in the crust of the earth and for the three of the common rocks cited. In granite, the rate of thorium occurrence is clearly four times

larger than that of uranium. Since uranium reserves will be studied later in this chapter, some light should be shed on the geographic locations of thorium in the world.

The commercially most important thorium-bearing mineral is monazite which is widely distributed over all continents. Other thorium bearing minerals of somewhat miner significance are thorite, thorianite and uranothorite.

Monazite takes the form of a sand with important deposits occuring along the sea shores of India, Brazil and Ceylon. Extensive deposits have also been found in South Africa, the Soviet Union, Scandinavia, Australia and North America with the main occurrences known in Idaho, Florida, and the ocean shores of the Carolinas.[29]

The mineral is normally recovered by dredging and concentrating through physical, mechanical means resembling very closely the uranium recovery method. Thorium concentrates contain between three and ten percent thorium dioxide.[30]

In Canada, thorium is officially recognized as 'closely associated mineralogically with both conglomeratic and pegmatitic ores.'[31] It has also been emphasized that the ratios of composition between thorium and uranium vary in these specific deposits. In the mining operations of Elliot Lake the rate was less than one. For the Agnew Lake deposits, however, that ratio was significantly higher as it was recorded between two and three parts of thorium to one part

of uranium.[32]

There was a time (1959-1969) when Rio Algom produced thorium for industrial users in Great Britain.[33] But since the end of that production "the thorium remains in the tailings", so one scientist laconicly remarked during a discussion. Let there be no doubt: there are other extensive thorium mineralizations in this country and these reserves are larger than they were in 1971.[34]

If the burn ratios of these two nuclear minerals are compared, it becomes evidently clear that the slow thorium breeder has a much greater potential (efficiency) than the conventional CANDU reactor because a much larger stock of thorium is convertible into fissile uranium 233 whereas only two percent of natural uranium (i.e. the U 235) is consumed in the fission process.

Professor B. Lewis pointed emphatically towards the economies - the savings that are obtainable from thorium utilization. Elaborating on the energy content of a fuel bundle of the types used in the Pickering Station he said that such a bundle "releases as much heat as would come from

> " releases as much heat as would come from burning 560 tons of the best coal. It contains about 20 kg U or 1/50 of a ton and 50 bundles would yield the equivalent of 28,000 tons of coal. As the abstract has it 'even the practical nuclear yields are tens of thousands of times as high as chemical energy yields'. The thorium fuel for CANDU-OC yeilds from a 30 kg bundle the equivalent of 3,200 tons of coal or more than 100,000 times the energy from 30 kg of coal. That is the yield before recycling which multiplies the yield before recycling which multiplies the yield about a further 8 times."[35]

In addition, the relative abundance of thorium over uranium in the world should not allow a fear of a shortage of mineral fuels to emerge in this time, even if the 'shortage syndrome' has been the general tenet of the 'Club of Rome'. That is why the same distinguished scientist from Queen's University was able to tell of his vision.

> "First, however, I must give you evidence that even if we have to pay more for energy in the next twenty years or so, the days of cheap energy are far from over, but have not yet come. They still lie ahead."[36]

In this sense, there is no doubt that nuclear mineral resources will last for centuries, especially in Canada,[37] and the world economies may be assured of continued growth and greater prosperity thanks to the role of a particle the existence of which was at first postulated about 60 years ago only to be really discovered in the 1930s after which it was put to work. In today's parlance, such developments are used as shining examples of the meaning of a very important term: technological change; and that as a change par excellence though not without aspects of imbedded risks.

SECTION II: URANIUM CONSUMPTION: DIFFICULTIES IN ASSESSMENT

Among the metals analysed in the context of this study none compare to uranium in difficulty to obtain consistent historical consumption statistics for the world and its consuming countries. That is simply why it has not been possible to include the consumption side explicitly into the computer analysis nor are the researchers sure that it would have produced better results for the forecast in Section V.

It has to be understood that uranium metal serves three completely different purposes such that the need for the metal is not identical with its annual consumption in reactors to generate electricity.

The three different categories of uranium application are:

1. Reactor usage;
2. Military requirements;
3. Other uses.

Reactor Usage

As to the use in reactors it is a standard procedure to determine the base load factor for each and every reactor and, thus, ascertain what is generally called 'committed' uranium quantities. The term 'committed U' refers to amounts necessary to keep a reactor running over a specific period of time which may be stipulated by law for a number of years.

The time of commitment in Canada is 12 years.

This base load requirement stems from the fact that a reactor has to burn a certain amount of uranium to maintain the chain reaction which lies somewhat above the 'critical point'. Should general demand for electricity be low, the reactor cannot be slowed down as is the case for thermal and even hydraulic powerplants or fuel cells. Were the reactor to be throttled below the critical point it would simply shut itself off. Therefore, once started it has to run until maintenance or other conditions require a temporary shut-off. Consequently, it would stand to reason that the minimum amount of uranium required for all existing and operating reactors on earth is almost absolutely certain.

In the same context, reactors under construction will, upon completion, exert a similar definite demand for uranium. However, the degree of certainty of the exact date of start-up of the reactor is subject to probable delays resulting from changes in direction of public policy towards nuclear energy generation exercised by the public at large in light of environmental dangers. There are, of course, other causes for delays, such as strikes, work-stoppages, security aspects and just technical problems, to name a few.

The third category included under the 'committed' uranium variety are those reactors to be built in the future and for which orders have been placed. Here, the degree of uncertainty

will be even greater than for the reactors under construction enhancing the variability for projected committed requirements.

The actual uranium absorption by running reactors has been very disappointing in the light of world-wide predicted consumption. As time passed on reactor requirements changed substantially year after year. Consider the year 1980. The actual burn-up stood in the neighbourhood of 18,300 metric tons of U_3O_8 in the Western World. However, the prediction in 1969 for 1980 had envisaged requirements of 78,900 metric tons.[38] Therefore, predictions on the base of uranium commitments are unreliable and leave much to be desired because they are two different things: one means the actual use while the other should imply the amounts of uranium which utilities are committed to acquire in the long run.

In the same vein of thought the actual destruction of uranium in the reactor process is also not properly stated, especially since spent uranium could be recycled were appropriate facilities available in all consuming countries. Therefore, the 'once-through' usage does not necessarily mean that for each spent pound of uranium a new pound must be mined. Should respective policies be developed in the course of time for all countries predictions as to future consumption by reactors would have to be revised. This marks a further difficulty in determining the amount of uranium that will be consumed.[39]

Furthermore, specific quantities of uranium are stored

as absolutely necessary inventories. When they are purchased they appear as uranium in the hands of utilities and wait to be consumed. No utility company with nuclear capability can run the risk of not being able to feed its reactor(s) for a certain number of years ahead. Therefore, these companies must pile up such inventories which are determined by expectations concerning the future availability and reserves, uranium prices as well as interest rates and changes therein, to name just a few factors. If prices are expected to decline while the interest rate is high there is a clear reduction in the need to hold a given quantities of inventories. Consequently the quantities demanded in the market by the users must decline. However, it is also clear that these economic factors may not be included when future committed requirements are taken into consideration in establishing overall consumption demand for uranium fuel. Note also that the manufacturers of reactors and those who produce nuclear fuels have to hold inventories, too ; so do the various uranium procurement organizations in all countries with nuclear reactors.

For the United States, some indication is given by the relation of inventories held to annual industrial use. According to the U.S.B.M. the ratio averaged 2.36 years inventory supply to consumption needs for the years 1969 to 1974,[40] excluding, of course, strategic stockpiles in military arsenals.

The NUEXCO established a similar ratio for the Western

World,[41] which, with a factor of 6.2 years supply, was much larger than the one set out by the U.S.B.M. This difference, though for two different time periods, only points to the difficulties one encounters when one includes inventories into the analysis. On the one side, there is enough uranium in inventories in the United States to last 2.4 years while world-wide stocks would hold out for 6.2 years on the other. Here uranium stockpiles by governments and procurement organizations are also included. In addition, there is some type of consensus that the stocks held by utilities only amounted to about two years of feed stock in 1980.[42] Therefore, the inventory variable would have to be disaggregated into its various components for the world as a whole.

The stockpile requirements would also change if one is to look at the possibility of recycling spent reactor fuels. Fuel savings would be substantial while the requirements for newly-mined uranium would be affected accordingly.[43]

Another interesting point has to do with the strength of uranium 235 content and the ore grade. Any qualitative increase of enrichment requirements would entail substantial variations in effectively needed uranium from the mines.[44]

Furthermore, there is the lead time required for mining, milling, refining,enriching and, finally, the processing of uranium into fuel proper. These separate functions have their own pecularities not only in the technical sense but also

when seen in light of governmental policies of the various countries. The outcome depends in no small measure on the given enrichment facilities in the world. The larger the requirements for uranium fuel, given a fixed enrichment capacity, the greater the lead time. In turn, this lead time may be shortened as more countries build their own enrichment plants and as the enrichment technology is improved and becomes more efficient. These changes would decrease the dependencies of the consuming countries on a few countries with enrichment facilities. This point, of course, holds only for light water reactors. The inclusion of the CANDU systems and their relative significance to the other reactor systems would likewise increase the complexity of the lead time, and, eventually, of the determination of uranium consumption.

It should therefore be clear that the concept of uranium consumption involves a large variety of factors and conditions in a considerable number of countries enhancing the technical complexity of determining consumption unless all these parameters could be quantified, which is highly unlikely for the average student without inside and classified information.

In short, uranium consumption is a complicated variable and outside the proper assessment by this study. At best, a technical relationship may connect the actual need for fuel and the mine demand for uranium. It should be added

that the price of uranium has played a relatively insignificant role for utilities in the past whose costs of reactors and of maintenance and operations has been highly capital-intensive such that fuel cost did not matter as much as the certainty of its availability.

And finally, this picture for uranium consumption for the world as whole becomes even more blurred were such a tabulation to incorporate reactor requirements and inventory aspects of the communist countries. Not even the NUEXCO does attempt to solve this problem even if some general information about the reactors in those countries is available as e.g. in Table 1. Such a study in depth lies outside the realm of the physical possible.

By and large, the world may look upon a total population of 530 nuclear reactors one day in the foreseeable future. This is a rough figure and is based on information taken by Lloyd from Nuclear News. This is ten more than listed because a number of existing reactors were not in operation. This was especially true for the United States where reactors had been shut down for inspection following the events at Three Mile Island.

This table separates clearly the number of reactors in the Western World from those in the centrally planned economies. 205, or 85 percent of all operating reactors in the world were located in the Western Hemisphere. This holds also

Table 1

Nuclear Reactors in the World

(In operation, under construction, and planned)

Country	In Operation	Under Construction	Planned
Western World			
Argentina	1	1	1
Austria	1	completed but under approval	
Belgium	3	4	-
Brazil	-	2	-
Canada	10	9	4
Egypt	-	-	1
France	21	23	8
West Germany	12	9	7
India	3	5	-
Iraq	-	-	1
Italy	4	3	2
Japan	21	8	1
South Korea	1	6	-
Libya	-	-	1
Luxemburg	-	-	1
Mexico	-	2	-
Netherlands	2	-	-
Pakistan	1	-	-
Philippines	-	1	1
South Africa	-	2	-
Spain	3	8	4
Sweden	8	3	1
Switzerland	4	1	2
Taiwan	2	4	-
Turkey	-	-	1
United Kingdom	34	5	-
United States	74	79	32 (1990)
Yugoslavia	-	1	-
Subtotal	205	176	68
Centrally Planned Countries			
Bulgaria	2	2	-
Czechoslovakia	2	4	3
Finland (Russ. technology)	2	2	-
East Germany	4	3	-
Hungary	-	4	-
Poland	-	2	-
Rumania	-	2	-
Soviet Union	26	13	?
Subtotal	36	32	3
TOTAL	241	208	71+

Source: Extracted from an article by, B.C.J. Lloyd, 'Uranium', M.A.R. 1980, p. 102-103, 'Total world units as given by Nuclear News, February 1980, were 530 representing 405,768 MWe. Caution has to be exercised in the interpretation of this table because experimental reactors carry as much weight as commercial reactors.

Table 1 continued

Reactor	Owner	Years In-Service	GW Capacity	No.
Operating				
Nuclear Power Demonstration	Atomic Energy of Canada	1962	0.02	1
Douglas Point	Atomic Energy of Canada	1968	0.20	1
Gentilly	Atomic Energy of Canada	1971	0.25	1
Pickering 1 to 4	Ontario Hydro	1971-73	2.06	4
Bruce 1,2, and 3	Ontario Hydro	1977-78	2.24	3
				10(9)*
Under Construction or Committed				
Bruce 4	Ontario Hydro	1979	0.75	1
Pickering 5 to 8	Ontario Hydro	1981-83	2.06	4
Gentilly 2	Quebec Hydro Electric Commission	1980	0.64	1
Point Lepreau	New Brunswick Electric Power Commission	1981	0.63	1
Bruce 5 to 8	Ontario Hydro	1983-86	3.08	4
				11
Planned				
Darlington 1 to 4	Ontario Hydro	1985-88	3.40	4
				4
			TOTAL	25(24)*

*Figures in brackets exclude the experimental 'Nuclear Power Demonstration' reactor.

Source: R.M. Williams " Uranium", Canadian Minerals Yearbook 1978, Energy Mines and Resources, Mineral Report 28, Ottawa, 1980, p. 487, Table 7, (n(s))

were located in the Western Hemisphere. This holds also for 176, or 84.6 percent,of those under construction. As to the reactors on the drawing boards in the communist countries not much is known yet. Therefore, the apparently high proportion of planned reactors in the non-communist world may be misleading if accepted without qualification.

In turn, it is also unmistakenly obvious that the U.S.A., France, the U.K., Japan, West Germany and Canada are the leading industrial nations with the largest number of atomic reactors in operation. No doubt, their economies rely already now heavily on this type of power supply and will increasingly depend on this energy source in the future. This may be seen from the reactor construction projects underway. It is also interesting to realize that the United States had planned to have 185 nuclear reactors in power plants by the year 1990, which is equivalent to 35.6 percent of that specific world total of 520.

Likewise, the Soviet Union is the indisputable industrial leader of the communist countries and, thus, disposes of the largest quantities of reactors among those countries. Still, all other countries of Eastern Europe seem to be well on their way to tapping the vast potential of nuclear power. This is brought out by the relatively equal number - between two and four for each country - of reactors under construction. In this respect they, too, have fewer under construction

than in operation just like the countries outside the Eastern block.[45]

Unfortunately, China had also to be deleted due to a lack of general public information. However, there is no doubt that this country has made great headway in the nuclear field with uranium reserves and reactor intentions left for the footnote[(152)] of Section IV.

Military Requirements

The pictures of Hiroshima and Nagasaki of August 1945 need no further elaboration. The detonation of these two atomic devices initiated the so-called 'Nuclear Age'. Today, two types of weapons are recognized: strategic and tactical. The former relates to the means by which certain powerful countries expect to maintain their country's security. The countries so involved in this particular type of military defense are the U.S.A., the U.S.S.R., the U.K., France, India, and China. There may also be some other countries whose covert intentions have eluded official international inspection and surveillance. No doubt, other countries may join the nuclear weapons club in the years ahead regardless whether or not they have signed the non-proliferation treaties.

The second type are the tactical weapons developed for ground support in actual theatres of operation in a potential conflict. These weapons do exist in a variety

of forms on both sides of the political spectrum of East and West sides of the globe. Not only the United States and the Soviet Union are keenly preparing to meet that awesome challange, but other countries,too-such as France-carry their own tactical nuclear arsenals.

In the context of this study, the immediate question arises concerning the quantities of uranium which have been absorbed annually since 1956 into the production of these weapons by the nuclear powers? That answer is simple. It has not been published as mystery and secrecy surround these figures on grounds of each nation's own security. Since these weapons exist, the uranium and the plutonium for their warhead have been produced from uranium that was mined. Can this be called consumption in the same sense as nuclear fuels are utilized in power reactors? Certainly not! but it is self-evident that the weaponry requires uranium to be put into these arms: therefore, there is a need for that purpose which relates to the demand for mined uranium. Yet, the application of uranium for nuclear weaponry must remain a big unknown for all countries so equipped or with the intention to join the military 'nuclear club'. This quantity cannot be incorporated into the consumption data. That is an additional and supportive argument why consumption figures are incomplete and unsuitable for proper analysis within the frame of reference of this study.

Other Uranium Uses

Besides the familiar fuel and weapons application of uranium, this metal serves other important commercial purposes than one is inclined to think at first. This additional usefulness of this metal should be demonstrated merely by a listing of its areas of service. The metal is needed in two forms: a) in its natural state and b) in depleted or spent form.

a) -in propulsion systems
- -for underground tests and rock blasting (of shale)
- -medical use of isotopes
- -early use in glass, ceramics and other chemical applications e.g. as catalyst
- -glass colouring and as coolant in the glass industry
- -as alloys in catalyst in the plastic industry
- -in the electrical industry in connection with X-ray tubes, specific electrodes and resistors.[46]

b) The depleted uranium which is void of any nuclear substance or particle is a very valuable resource:
- -its high density provides for a better radiation shield than lead making for lighter containers of radioactive materials
- -as counterweights in space vehicles, missiles and aircraft
- -military application in special equipment parts, ammunition and specialty shells, especially as alloys with molybdenum and titanium.[47]

Understandably, spent or depleted uranium is, from the economic point of view, a by-product of an industrial con-

sumption process which again becomes an input. It is obvious that this new product is available in such large volume from the vast masses of fuel burnt that only 10 percent of the spent uranium finds industrial application.[48] As such it does not affect the consumption needs of uranium nor the demand for mined uranium in a positive way, if at all. To be sure, spent uranium does not mean radioactive waste but a purified product.

SECTION III: THE PRODUCTION OF URANIUM U_3O_8

Western World, Canada and Ontario (1956-1979)

Hence forward, the term 'world' comprises of the countries outside the communist orbit[49] and by uranium is meant uranium U_3O_8 unless otherwise specified. In this sense the world produced 13,124 metric tons of uranium in 1956, the year since when consistent production statistics are available. In the year 1979, uranium output had been rising to an annual total of 44,977 metric tons as shown in Table 2. This was equivalent to an increase of 242.7 percent over the entire timespan from 1956 to 1979. This sharp rise of production, however, is not evident when average annual outputs of the first and last five years are compared with each other. The former average stood at 28,746.4 metric tons while the latter was computed at 32,006.4 metric tons reflecting a rate of growth over the entire period of 23 years of about 11.15 percent, or by annual percentage point additions of merely 0.48 of one percent.

What happened? The answer to this simple question is illustrated in the same Table. Output of uranium shot up in those earlier years. By 1959 annual production had reached 39,318 metric tons. In the following years, annual production declined to the 17 to 19,000 metric ton level (1965) and stayed that low for a ten-year period until 1975 inclusive. Thereafter it started to climb and it was only in 1978 that

Table 2

Western World and Canadian Uranium Production
And Canada's and Ontario's Significance as World Producers
For the Years 1956 to 1979
In Metric Tons and Percent of World Output

Year	World Metric Tons	Canada Metric Tons	Canada %	Ontario %
1956	13,124	2,068	15.76	3.13
1957	21,106	6,019	28.42	17.13
1958	32,879	12,156	36.97	27.54
1959	39,318	14,414	36.66	29.40
1960	37,305	11,562	30.99	24.06
1961	32,924	8,744	26.56	20.62
1962	31,292	7,646	24.43	18.56
1963	28,145	7,577	26.92	20.58
1964	23,772	6,609	27.80	22.53
1965	18,653	4,031	21.61	16.60
1966	17,731	3,567	20.11	15.03
1967	17,325	3,391	19.57	14.27
1968	20,870	3,357	16.09	11.65
1969	17,557	3,420	19.48	14.97 est.
1970	18,201	3,234	17.77	14.45
1971	18,581	3,160	17.01	14.51
1972	19,880	4,000	20.12	17.37
1973	19,773	3,710	18.76	16.00
1974	18,472	3,420	18.51	15.71
1975	19,080	3,510	18.40	15.99
1976	22,293	4,850	21.76	15.07
1977	33,924	6,827	20.09	12.60
1978	40,008	8,022	20.05	11.16
1979	44,977	8,136	18.09	11.49

Source: United Nations, Statistical Yearbook, New York, N.Y.; and Technical Information Paper, No. 2, Table 9, p. 18.

the peak performance of the year 1959 was finally surpassed. Therefore, the world uranium industry had suffered a substantial setback lasting for almost two decades. In short, after a brief and strong initial surge in the production of a mineral which came to fame and sudden demand by a revolutionary technological innovation, that demand declined and so did output. This was especially true since the apparent consumption of the metal as fuel was only a fraction of output such that a huge stockpile of uranium had been created.[51] In this sense, uranium is the only metal under investigation which differs fundamentally in its mining output performance from all other metal in that it did not display some type of a continuous upward trend over that period. The world uranium industry, during its short history of existence, has been exposed to an unusually long run swing with a large amplitude in output covering a timespan of twenty years.

Canada

Canada's uranium output in 1956 stood at 2,068 metric tons and rose to 8,136 metric tons by 1979. The apparent annual difference of a growth factor of 293.4 percent is, of course, similarly deceiving as for the world as a whole. When measured against the averages of the first and last five years, an actual decline from 9,243.8 to 6,269 metric tons is clearly noticeable. This means a reduction by -32.18 percent over the period. Therefore, the Canadian uranium industry

has performed worse than the world as a whole!

In 1959 it produced 14,414 metric tons which is still the unsurpassed production peak. Even in 1979, when 8,136 metric tons were mined, that previous peak was still out of reach by 6,278 metric tons to be repeated! This means that Canada's uranium industry absorbed the slump to a larger degree than the remaining uranium producing countries in general. This performance testifies to the fact that the Canadian uranium mining industry is much more vulnerable than the industries in other countries including the United States.

Ontario

In 1956, the uranium industry of Ontario started at a very low level producing 19.88 percent of uranium ores compared to Saskatchewan which then was the main supplier (60.96%), while the Northwest Territories were almost as important as the Province of Ontario.

This picture changed rapidly from 1957 on when the Province of Ontario accounted never below 63.53 percent-in 1979-of all uranium mined in Canada. Ontario's greatest relative share stood at 86.90 percent in 1975.[52] In recent years, a relative decline set in for Ontario as Saskatchewan started again to forge ahead strongly in uranium mining staging something like a 'come-back'. This is due to the discovery of large and extraordinarily rich uranium orebodies.

On a world scale, Ontario supplied closely to 30 percent of the world total in 1959, the peak year of Canadian uranium production. Ever since, a gentle decline in this distribution eroded Ontario's significance as a world uranium producer with the exception of the year 1972 when 3,822 metric tons were mined in the Province amounting to 17.37 percent of the world total.[53] However, at the end of the decade Ontario's position in the world uranium field was between 11 and 11.5 percent. It represented a decline from 30 percent but still had to be judged as large considering the new entrants to the world uranium scene since 1956.

The Main Uranium Producing Countries

The United States is, unquestionably, the most important of all uranium producing countries (Table 3). Its share in world output has consistently been above 40 percent of the total until the 1970s when other countries such as Niger, Gabon and Australia moved strongly into the field of uranium mining. It is of special interest that during those difficult years in which the uranium mining industry found itself the United States was able to raise its relative share from 40 to 50 percent. This meant that the United States decreased its uranium output at a lower rate than the other producing countries such that the industry outside the U.S.A. carried a greater burden a country which is the chief

Table 3

World Production of Uranium (Non-Communist World)
And Distribution by Main Producing Countries
For Selected Years Between 1956 and 1979
In Metric Tons of U_3O_8 and Percentages

Year	1956	1960 1)	1965	1966	1970	1975	1979 2)	
World Total in Metric Tons	13,124	37,306	18,653	17,731	18,201	19,080	44,977 3)	Rank
Country	%	%	%	%	%	%	%	#
Argentina	-	-	0.1	0.1	0.2	0.1	0.5	
Australia	2.1	3.2	1.8	1.7	1.4	n.a.	1.6*	
Brazil	-	-	-	-	-	-	0.3	
Canada	15.8	31.0	21.6	20.1	17.8	18.4	18.1	(2)
France	-	3.4	6.9	7.8	6.2	9.1	6.1	(6)
Gabon	-	-	3.5	3.2	2.2	4.2	2.6	(7)
Namibia	-	-	-	-	-	-	9.7	(4)
Niger	-	-	-	-	-	6.8	8.7	(5)
Portugal	-	-	0.2	0.2	-	0.6	0.2	
South Africa	30.2	15.6	14.3	16.8	17.4	13.0	13.6	(3)
Spain	-	-	0.3	0.3	0.3	0.7	0.9	
United States	41.5	43.2	50.8	49.0	54.4	46.6	37.7	(1)
Total	89.6	91.4	99.5	99.2	99.9	99.5	100.0	

Source: United Nations, Statistical Yearbooks, «Uranium», New York, N.Y.

1) Zaire produced: 1,179 metric tons or 8.9% of the total in 1956; others: 1.5%
1,088 metric tons or 2.9% of the total in 1960; others: 0.7%

2) For most countries the figures for 1979 represent planned quantities expected to have been produced.

3) Also note that the world total for 1979 is taken from M.A.R. 1980, p. 103.

consumer of the fuel metal.

In the year 1956 South Africa was the second largest among the world's uranium mining countries but lost this position to Canada in the 1960's. By 1979, Canada still held onto 18.1 percent of the total while South Africa stayed in third place with 13.6 percent followed by Namibia with 9.7 percent as the share of world uranium output. If this output of fourth-place Namibia coming from the Rossing mine[54] is included under the production figures of South Africa, a total of 23.3 percent would be commanded by this combination of countries which would place them ahead of Canada.

Niger came to the forefront as a uranium producer only during the 1970s and succeeded to rank as the fifth largest supplier (8.7% in 1979). France, in turn, is the next producer of importance holding 6.1 percent of world output in 1979. The last of uranium mining countries with a share greater than two percent is Gabon. It commanded 2.6 percent in 1979 which actually represented a decline after it had held already 4.2 percent in 1975. In 1979 it mined about 1,180 metric tons compared to 1,660 metric tons in 1977, and to 800 metric tons in 1975.

No doubt, Australia is the country to be watched during the next two decades as it is quickly developing its substantial uranium deposits. Its impact on the world

distribution is already recognizable considering that it produced 1.6 percent of the total in 1979 while for the year 1980 its share had risen to 3.8 percent.

Canada's Trade in Uranium

(Radioactive Ores and Concentrates Commodity Item 259-55)

The Years 1955-1971

Canada has always been a strong exporter of uranium during the entire period from 1955 to 1980'81 and its balance of international trade has benefitted greatly from this trade. The export quantities, however, are not listed in Canadian trade statistics. Only the values of shipments are recorded! Since there were essentially no imports of uranium into Canada, column (3) of Table 4 reflects this benefit as expressed in nominal (current) Canadian dollars. To the extent that imports occurred, certain reexports are recorded, though only during the years from 1958 to 1961 at the height of the first uranium boom.

Starting with an export value of $Can 26.5 million in 1955 Canada reached an export value of $Can 312 million in 1959. Until 1957 inclusive, the United States had been Canada's principal and only customer. From 1958 on, however, the United Kingdom became what was to be our most reliable client which is conceivable from the consistency displayed by British import values of Canadian uranium over almost the entire period of time. Except for the years 1970 and

Table 4

Uranium Output of Canada and the United States

For the Years 1956 to 1979

Value of Canadian Shipments of Uranium Ores and Concentrates*)

To the World, the U.S.A. and the U.K.

For the Years 1955 to 1981 (June)

	Production of U_3O_8 Metric Tons		Value of Canadian Exports of (C.I. 259-55) Uranium Ores and Concentrates (Radioactive Ores and Concentrates)		
Year	U.S.A. (1)	Canada (2)	World (3)	U.S.A. (4)	U.K. '000$Can (5)
1955			26,533	26,533	
1956	5,442	2,068	45,777	45,777	
1957	7,836	6,019	127,935	127,934	1[1)]
1958	11,401	12,156	276,506	262,675	13,503
1959	14,893	14,414	311,904	278,913	32,603
1960	16,108	11,562	263,541	236,594	25,905
1961	15,781	8,744	192,722	173,914	18,256
1962	15,428	7,646	166,009	149,165	16,598
1963	12,898	7,577	137,531	96,879	40,509
1964	10,747	6,609	74,653	34,862	39,627
1965	9,473	4,031	53,698	14,749	38,949
1966	8,697	3,567	36,366	13,761	22,605
1967	8,278	3,391	23,874	1,047	22,772
1968	11,403	3,357	26,067	3	26,064
1969	8,900	3,420	24,507	477	14,996
1970	9,900	3,234	26,021	17,032	8,990
1971	9,929	3,160	17,687	5,899	11,473
1972	9,900	4,000	39,496	23,039	16,456
1973	10,200	3,710	64,150	46,794	17,356
1974	8,900	3,420	51,309	24,904	21,627
1975	8,900	3,510	47,052	28,129	17,937
1976	9,800	4,850	67,392	46,850	20,541
1977	13,514	6,827	75,438	72,848	2,590
1978	16,780	8,022	207,156	163,911	39,106
1979	16,961	8,136	378,862	347,388	18,851
1980			280,662	209,978	10,319
1981 (June)			32,433	16,509	10,720

[1)] rounded from $800.

1977, annual exports never dropped below a value of \$Can 10 million.

In contrast, exports to the United States underwent drastic changes during this time. As Canada's uranium industry had been built in response to ever-increasing needs to the south of the border, a definite dependency existed for the industry on what happened down yonder. The initial strong demand for Canadian uranium exports had their source in the defense requirements of the United States. However, the day came that the two major participants in this nuclear game - the U.S.A. and the U.S.S.R. - had nuclear arsenals large enough to kill their populations and those of the remainder of the world n-times over. The rate of nuclear weapons growth seemed to slow down and with it the need for uranium. The time of detente had arrived.

During the same years, the requirements for reactors to generate electricity were still a fraction of annual world potential with the unavoidable result that uranium production in the western world fell off sharply. In addition, the uranium industry in the United States was able to exert sufficient pressure on the government leading to an import embargo which had been preceded in 1959 by the Atomic Energy Commission of the United States not taking up further options on imports of uranium from Canada. This was in spite of pleas by the Canadian government authorities to reconsider

and possibly to modify a plan which was to create havoc in the Canadian uranium industry.[55] Eventually, the Atomic Energy Commission (U.S.A.) prohibited the use of foreign uranium, even if it had been enriched in the United States. This measure meant a modification of the embargo since it left a door open for stockpiling and forward purchases.[56]

The consequences of these policies are obvious for anyone studying the uranium export performance as shown in Table 4. From $Can 278.9 million world of uranium exports to the U.S.A. in 1959, U.S. imports virtually disappeared as in 1968 a total of three thousand Canadian dollars worth of uranium were shipped to the neighbouring country in the south. This meant a reduction to one hundred thousandth of the peak export value to the U.S.A. of the year 1959!

This policy did not fail to show very positive effects on the uranium industry in the United States. While Canadian output declined from 3,391 metric tons in 1967 to 3,357 in 1968 - or by - 2 percent, the output in the Western World rose by 20.5 percent from 17,325 to 20,870 metric tons. For the same two years uranium production in the United States rose by 3,125 metric tons from 8,278 to 11,403 metric tons or by 37.8 percent. The Canadian uranium mining industry proved highly vulnerable to external factors, especially to conditions and events taking place in the United States, our main trading partner, as we thought.

In order to absorb the worst repercussion which such measures had on the industry, the Canadian taxpayers came to the rescue of this sector of the Canadian mining industry. The Canadian government began to purchase and stockpile uranium. In 1970, the stockpile was reported to have reached "9,650 tons of uranium", or about three years production. By that time a second stockpile was being started in cooperation with Denison Mines.

In 1971, annual export value of Canadian uranium had dropped to 17.03 million after the United Kingdom had lowered its imports from Canada especially in 1970.

The Uranium Cartel

Between February 1 and 4, 1972 an organizing meeting was held in Paris by government representatives of the uranium producing countries of Canada, Australia, France and South Africa who were joined by representatives from the Rio Tinto-Zinc Corporation. After several meetings centering on the market arrangement and on legal aspects of cartels and government involvement the cartel was finally launches in the middle of that year. A market bid mechanism working through cartel-determined price schedules and market distribution schemes with quotas were agreed upon and implemented. Surveillance of operations was in the hands of a secretariat to guard against violations of the cartel agreement by firms of participating countries. Penalties for infringement on such

contractual cartel commitments called forth fines in terms of "dollars, tonnage, and quotas".[58]

Objectively speaking, it has to be realized that producing countries of the Western World outside the United States had accumulated substantial stockpiles of uranium. Besides, Canada, France, too, held great inventories reported in the neighbourhood of 10,000 tons at the time.[59] They faced the following alternatives: either the stockpiles or part of them could be sold or the industry would have to curtail production further until market conditions improved. The fear of international dumping introduced a degree of urgency into the atmosphere as governments who had subsidized the industry tried to recoup the invested funds. A tight allocation scheme with upward moving prices and the stipulated removal of all fixed prices in the (forward) contracts after 1978 were some of the special features which aimed at improving the market for both the industry and the concerned governments with a view of reducing stockpiles while simultaneously escaping from fixed low prices in future contracts which seemed to have kept uranium prices from rising.

The interesting point is that this cartel was created with the apparent cooperations of governments at more than a full year before the OPEC price hike.

The price rise of uranium was initiated by the cartel but it obtained additional momentum and considerable uplift

from the rise of the price of crude oil and, subsequently, of energy. Furthermore, it has been argued by Canadian experts in this field that,due to the peculiar nature of the consumption, demand and production relationships, the market, then, had been ready for a long overdue reversal[60] of the downward trend in uranium prices. It was said that the industry was about to pick up anyway. On these grounds the cartel would have been unnecessary. In turn, OPEC's hike of oil prices the independent reversal of the downward trend of the uranium market and the cartel arrangement catapulted the uranium price to its unprecedented heights, while the market had been primed for events to come.

Let it not be forgotten that the threat of scarcity for any product will force prices of that commodity up as users start to scramble for supplies to secure their consumption needs. Here, it was the scramble for supplies to secure reactor operations far into the future. In this context, forecasts of demand and supply emanating from respectable international and national organizations - private and public - became helpmates in bringing across the fear of danger that demand would outstrip supply. Simple mathematical growth models flourished well in a doomsday atmosphere of limited resource availability propagated by the 'Club or Rome'.[61] Such non-functional models exclude crucially important factors such as price behaviour,

aspects of technological change and general economic performance as well as market structure. No question, these models are superb and elegant in all their mathematical formulations but their rigour and the underlying assumptions help create conditions untenable in the long run!

The price improvements aimed at by the cartel came about much faster than the cartel participants could have dreamed of when they set it up. The combined effect of the cartel, the push by OPEC and exaggerated demand predictions under fixed uranium reserve assumptions succeeded in accelerating uranium prices drastically.

Early in 1975, the cartel ceased its operations and it transmigrated across the Channel to London in the new form of the Uranium Institute. A pound of uranium did cost $US 20/lb ($U_3O_8$) reaching an average of $US 23.68/lb ($U_3O_8$) for that year. It had also become clear that the United States would lift the embargo in 1977/78. However, there was to be an aftermath to the cartel affair because certain companies were unfavourably affected by these soaring uranium prices and a U.S. politician, Congressman John Moss got wind of the cartel.[62]

The company in difficulties and willing to take action turned out to be Westinghouse. This is an electrical company- not to say industrial giant- which also happens to build nuclear reactors. Whenever it sold such a piece of capital equipment it used to include in the contract, for a sweetener,

a full supply of reactor fuel over the life of the reactor at a <u>fixed</u> (low) price.[63] With the accelerating upward movement of uranium prices Westinghouse encountered severe problems in acquiring uranium at prices close to the ones at which it had contracted to deliver fuel to its customers.[64] Supplies started to run short as the price has surpassed that $US 20/lb limit. In October of 1975, Westinghouse declared its inability to honour its uranium fuel supply commitments. The utilities, for fear of both immediate and long run shortages, jumped into the market and drove the price of uranium over $US 44/lb.Westinghouse blamed the cartel for its difficulties.[65]

A variety of legal disputes ensued and the matter is still before the courts. For instance, the Justice Department of the United States investigated the anti-trust aspect of the the cartel in the United States fining Gulf Minerals $ 40,000. And 17 companies, mostly utilities, took Westinghouse to court for breach of contract. Westinghouse, in turn took legal proceedings against 17 American and 12 foreign firms including Rio Algom, Gulf Mineral, Denison and Noranda to court in Chicago for treble damages of $6 billion: The Chicago 29. About nine companies did not appear in court in the capital of the midwest and, subsequently, had their assets frozen as they were in default. Since mostly foreign companies were

involved, the governments of Australia, Great Britain and Canada had passed measures preventing these companies from divulging privileged information. As matters stand, the court has moved to Toronto in September 1981 and the outcome of this far-reaching court battle is being awaited with great interest.[66] It should not be forgotten that Westinghouse may see this as a splendid opportunity to return the "favours" of the electrical industry for the beating they took in the 1960s when ten of them were convicted of price-fixing with treble damage suits coming from clients such as TVA, while some of the top executives went to jail for a month!

In Canada, the Honourable Warren Almond, then Minister of Consumer and Corporate Affairs, ordered an inquiry pursuant to paragraph 8(c) of the Combines Investigation Act into uranium marketing in Canada.[67a] The question to be answered by this investigation is whether or not the cartel arrangement may have led to violations under the Act. The result will be interesting considering that the Canadian government was directly involved in this marketing arrangement and had been warned by Dr. Henry, then, the very respected director of the Combines Investigation Branch of the Federal Government in Ottawa.[67b]

Canadian Uranium Trade 1972-1979 (-June 1981)

As other countries besides the United States -the United Kingdom and France-became producers of nuclear power,

a certain though unspecified volume of Canadian exports was actually destined for reexports to end-user nations If these countries in question were utilizing light water reactors, the uranium of Canadian origin would be enriched under contract in the United States after which it would be shipped to the end-users. Therefore, any change in the value of shipments to the U.S.A. may likewise contain and reflect upon such U.S. reexports of Canadian-mined uranium. Therefore, international shifts of demand for uranium away from Canadian raw material may explain quite sudden drops in export receipts, but not the reason for those shifts!

As Canadian uranium exports receipts had fallen to $Can 17.7 million the effect of higher prices - not to say of the cartel - led to a noticeable improvement in the uranium export balance. Receipts from uranium shipments were $39.5 million in 1972 (Table 4) of which 23 million came from the United States. By 1973, export values to the United States doubled while overall exports climbed to a value of $Can 64.1 million. In the following years, a decline in export receipts set in while actual annual production of uranium in Canada remained relatively stable though at fairly depressed levels (Table 4). By then, exports to the United States had fallen to a value of $Can 26.5 million even though, then, the cartel officially did not exist any longer.

In the year 1976, the value of Canadian uranium exports

rose as output, too, started to advance. This means that it took a lag of four years of stable levels of production until the uranium industry saw it worth its while to step up production! In 1977, uranium exports valued $Can 75.4 million with exports to the United States accounting for $Can 72.8 million. With both the end of the embargo and rising prices uranium exports soared to $Can 207 million in 1978 of which 79.1 percent went to the United States. The value of uranium sales in the following year (1979) scored an all-time high with $Can 378.9 million in receipts whereby shipments to the south of the Canadian border contributed $347.4 million or 91.7 percent.

If one is to extend the discussion beyond the limit of 1979 as applied to the other metals in this study, the picture changes quite dramatically. As the spot price of uranium started to turn in a downward direction export values for 1980 decreased to 280.6 million and the share allocated to the United States had fallen to 74.8 percent. Exports of uranium to the U.S. were $Can 210 million meaning a decline of 39.6 percent.

For the first half year of 1981, the picture is even more dismal. Until June of 1981 only $Can 32.4 million were exported with only half of it attributable to sales to the United States. Compared to the half-year performance of the previous year, total receipts were down by 77.8 percent

which can only be to some degree explained by weak uranium prices not to mention fixed contract prices. As the price reached $US 24.25 in June of 1981 [68] the quantities must have fallen off as well!

Take also note of what has happened in the uranium trade with the United States. The value of shipment decreased by no less than 87.6 percent in this half year in comparison with 1980, as $Can 132.858 million worth of uranium were sold to the United States in the first six months of 1980 while only $Can 16.509 million were exported to this important customer!

However, the overall outlook is not too bad, for, in the meantime Canada, has found a new customer: the U.S.S.R.(!) to which $Can 3.182 million worth of radioactive ores and concentrates have been sold during the first half of this year, 1981.[69] This marks a new leaf in the annals of Canadian trade which the classical-minded economist may welcome as a confirmation of the viability of the old (liberal) free trade doctrine.

SECTION IV: URANIUM RESERVES AND ALTERNATIVE SUPPLIERS

This section discusses at first the magnitude of uranium resources and subsequently their distribution among main reserve-holding countries. However, the main part of this section is devoted to an exposition of uranium investments and output potentials of the chief producing countries. Observations made for other potential suppliers have been tucked away into footnote 152.

There are three types of resources of uranium: secular resources, and long and short run reserves.

1. The secular resources consist of speculative uranium deposits which await discovery plus long-run reserves.
2. The long-run reserves comprise reasonably assured plus additional estimated reserves economically feasible for extraction at a price of up to \$50/lb of U_3O_8, whereas
3. The short run reserves refer only to reasonably assured reserves and feasible for exploitation up to a price of \$30/lb, all expressed in U.S. dollars.

Uranium Reserves and Resources

During the infancy of the nuclear industry uranium was considered a very 'scarce' metal. However, over time the stock of mineral reserves and potential resources grew with the expansion of the industry itself. Exploring for uranium

became technically more sophisticated and, thus, more productive as larger and larger quantities of economic grades of ores were discovered beyond what had been thought possible at given prices. For instance, the quantities of ore reserves of the Western World at a price (cost) of \$10/lb in 1970 had been estimated at 761.000 metric tons of U_3O_8, as brought out in Table A2 in the Appendix to this chapter. Three years later that reserve, at the same price, had risen to 961,800 metric tons.[70] In 1975, and at a price of \$15/lb, 1,080,000 metric tons were counted as reserves which were extended to 1,393,000 metric tons were the price (cost) to go to \$30/lb of U_3O_8. In 1977, the same bench-mark price of \$30/lb would have provided for a reserve of 1,562,000 metric tons while by 1979 the INFCE group, now introduced \$80/kg of uranium (U) (or \$36.28/lb) and estimated the reserves as 1,855,000 metric tons which ought to be equivalent to 2,188,900 metric tons of U_3O_8. By then, a possible additional estimated reserve of 1,480,000 metric tons of uranium (U) (or 1,746,400 metric tons of U_3O_8) at the same price would have had to be included for a total of 3,335,000 metric tons of uranium (U) (or 3,935,300 metric tons of U_3O_8)[71] Consequently, with the passage of time the quantities of available uranium and those to be expected as reserves have been on the rise!

In June of 1978, the Nuclear Energy Agency (NEA) of

the OECD and the International Atomic Energy Agency (IAEA) through the special study group for the International Uranium Reserve Evaluation Project (IUREP) which had begun work in late 1976 presented its final report. Based on most recent geological information it gave a new insight into speculative mineral ore resources beyond the - 'reasonably assured' and 'additional estimated' - reserves (Table A3). This was a global study comprising 185 countries. It envisaged a uranium resource potential of between 9.9 and 22.1 million metric tons of uranium (or between 11.67 and 26.06 metric tons of U_3O_8) including also the speculative reserves of Eastern Europe, the U.S.S.R. and the People's Republic of China.

One year later NEA/IAEA published a new survey of estimated normal reserves which added 1.85 million metric tons (U) of 'reasonably assured' and 1.49 million metric tons (U) of 'additional estimated' reserves at a price of about \$36/lb (U) to the total; at a price of about \$60/lb (U) the 'reasonably assured' and 'additional estimated' reserves totalled 2.586 and 2.44[6] million metric tons respectively (or 3.051 and 2.886 million metric tons of U_3O_8 at about \$50/lb (U_3O_8) as set out in Table 5. These reserve totals would have to be added to the speculative mineral ore resources.

Therefore, global uranium resources were calculated

Table 5

World Uranium Reserves and Their Distribution by Main Holding Countries in Thousand of Metric Tons and Percentages

	at about $\$30/U_3O_8$					at about $\$50/U_3O_8$			
Country	(Short-run)	%	Additional Estimated	Total	%	Reasonably Assured	Additional Estimated	(Long-run)	%
World	1,855	100.00	1,480	3,335	100.00	2,586	2,446	5,032	100.00
Australia	290	15.63	47	337	10.10	299	53	352	7.00
Brazil	74	3.99	90	164	4.92	74	90	164	3.26
Canada	215	11.59	370	585	17.54	235	728	963	19.14
France	40	2.16	26	66	1.98	55	46	101	2.01
Gabon	37	1.99	0	37	1.11	37	0	37	0.74
Namibia	117	6.31	30	147	4.41	133	53	186	3.69
Niger	160	8.63	53	213	6.39	160	53	213	4.23
South Africa	247	13.31	54	301	9.03	391	139	530	10.53
United States	531	28.63	773	1,304	39.09	708	1,158	1,866	37.08
Others	144	7.76	37	181	5.43	193	123	316	6.28
World (U_3O_8)	2,188.9		1,746.4	3,935.3		3,051.5	2,886.3	5,937.8	

Source: R.E. Green and R.M. Williams, Nuclear Energy - One Road to Self-Sufficiency, Atomic Energy of Canada Ltd., April 1980, 94th Annual Congress, Engineering Institute of Canada, Calgary, April 23-25, 1980.

Note: The quantities given in this table refer to uranium (U), not U_3O_8; also the original prices as stated in $/kg(U) have been translated into $/lb of U_3O_8. they are directly applicable to the last row of figures only. Prices for the left side of the table were $80/kg (U), and for the right side $ 130/kg (U).

to lie between 14.9 and 27.1 million metric tons of uranium (or between 17.58 and 31.98 million metric tons of U_3O_8). For the Western World, the respective magnitudes ranged between 11.6 and 21.8 million metric tons of uranium (U) or between 13.69 and 25.72 million metric tons of U_3O_8. They should be considered the <u>speculative secular reserves</u>.

In the long-run sense, total reserves of the Western World should include all potential ores which would be commercially feasible for extraction at a price of about \$60/lb of uranium (U) or of about \$50/lb U_3O_8. They amount to 4.032 and 5.9378 million metric tons in terms of uranium or uranium oxide (yellow cake (U_3O_8)) respectively (Table 5). In turn, the short-run reserves are those reasonably assured at the price of about \$36/lb of (U) or of about \$30/lb of U_3O_8. They amount to 1.855 and 2.1889 million metric tons of uranium or its oxide respectively (Table 5, left most column).

The following breakdown summarizes the uranium resource picture in million metric tons:

Resources:		Million of Metric Tons		
Secular	Global	14.9-27.1	17.58-31.98	RAR+EAR+SP[73]
	Western World	11.6-21.8	13.69-25.72	RAR+EAR+SP
Long-Run Western World				
at \$60/lb(U)		5.032		
at \$50/lb(U_3O_8)			5.9378	RAR+EAR
Short-Run Western World				
at \$36/lb(U)		1.86		
at \$30/lb(U_3O_8)			2.1889	RAR

Distribution of Main Reserve Holding Countries

Since the interest dwells mainly on both short-run and long-run reserves they will be dealt with explicitly while size and distribution of the speculative resources has been reserved in summary fashion for Table A3 of the Appendix to this chapter. However, it should be taken ahead of the discussion that the international research study group allocated a speculative potential of 1.0 million metric tons of uranium (1.18 million metric tons of U_3O_8) to Canada which, according to Green and Williams, corresponds to values ascertained by EMR[74] in the range of 1.0 - 1.2 or 1.18 - 1.42 million metric tons of uranium and its oxide respectively.

The various short and long run reserves of the main reserve countries and their percentage distributions have been set out in Table 5. Accordingly, the United States is the most important uranium storehouse in the Western World accounting for 531,000 metric tons (U) (or 627,000 metric tons of U_3O_8) in the short run or for 28.6 percent of the total distribution. The second most important country is Australia holding 290,000 metric tons of uranium - 342,200 metric tons of U_3O_8 - or 15.63 percent of the total. South Africa is in third place with 247,000 - or 291,460 metric tons of uranium and uranium oxide respectively for 13.3 percent of all reserves. Were Namibia's 117,000 metric tons of uranium - 138,000 metric tons of U_3O_8 - be included South

Africa could account for 19.6 percent of the world reserve total, putting this country into second place instead of Australia! Canada is the fourth largest holder of uranium reserves with 215,000 metric tons of uranium - or 253,700 metric tons of U_3O_8 - which is equivalent to 11.6 percent of the total. Niger (8.6%), Brazil (4.0%), France (2.2%), and Gabon (2.0%) follow in rank of importance as uranium reserve holders. It is also clear that this picture would change very much in Canada's favour were additional estimated reserves at the price of $36/lb (U) or $30/lb ($U_3O_8$) be included. In this sense Canada (column 4) possesses 585,000 metric tons of uranium - or 686,760 metric tons of U_3O_8 - and would place second behind the United States with its 1.3 million and 1.5 million metric tons of uranium and uranium oxides respectively. Indications are that the rate of uranium discoveries has been excellent in recent years such that the given short-run figure of 215,000 metric tons is on the conservative side.[75]

As to the long-run reserves, Canada would most likely benefit greatly from a world-wide expansion of uranium consumption. Here, overall reserves of 5.0 million metric tons give Canada a total of 963,000 metric tons of uranium or 1.136 million metric tons of U_3O_8. This is 19.14 percent of the total of the Western World's uranium deposits making Canada unquestionably into the second most important

supplier of uranium in the long-run after the United States with 1.87 million metric tons (U) or 2.21 million metric tons of U_3O_8 or 37.09(!) of that total. In short, the United States and Canada would be expected to have command over 56.22 percent of the total reserves of the Western World! In this long-run context South Africa is third in line (10.53 %) followed by Australia (7%), Niger (4.23%), and Namibia (3.69%). Were Namibia to be counted as part of South Africa that sub-total would amount to 14.22 percent leaving Canada the uncontested second position. South Africa-cum-Namibia, however, would have changed ranks by moving into third place. Surprisingly, Sweden is high on the list of long-run competitors as a result of its extensive Ranstad shale deposits. However, it is argued that they "may never be exploited on a significant scale for environmental reasons."[76]

Therefore, Canada is the world's second largest holder of uranium long-run reserves. This means that Canada will have at its disposal a much greater supply of uranium than other countries and it alone could provide almost 20 percent of the uranium needs in the Western World.

Alternative Suppliers and Investment Activities

In this subsection investment activities in the main uranium producing countries will be explored. However, this approach differs from that of other metals under study in

that, as an exception, Canadian developments will also be dealt with because they are massive by any standard of comparison and because they tie in closely with the various firms in the international network of uranium producers! The countries to be examined are:

Australia
Canada
Namibia
South Africa
Gabon
Niger
United States
and others.

Australia

Uranium Production 1956:		272 metric tons
	1979:	707 metric tons
	(1980):	1,840 metric tons

Numerous and substantial uranium investment activities are taking place in Australia. Even Canadian interests are involved as, for instance, in the uranium deposit of Koongarra in the Northern Territories. This property was purchased by Denison Mines from the Noranda Group. The intentions are to open it up at a cost of $A80 million to produce 1.133 metric tons of U_3O_8 annually.

Another project is contemplated by Pancontinental Mining Limited (65%) and Getty Oil Developments (35%). This joint venture wants to invest $200 million in Jabiluka in

the Northern Territories in the form of an underground mine plus, possibly, a concentrator. According to more recent information the target output has been revised to 4,500 metric tons of U_3O_8 from 3,000 metric tons with gold as a by-product. The project, hopefully, will be completed by 1985.[76]

The third of the major uranium development projects is being undertaken by the Ranger Consortium. It is investing $250 million to create an output capacity of 2,550 metric tons annually which should be in operation in October 1981. Eventually, that capacity will be increased to 5,000 metric tons of uranium once market conditions permit.[77]

Also, the uranium potential of the Western Mining Corporation should not go unmentioned. This corporation has committed $365 million to build an open-pit mine and a concentrator plant at Yeelirrie, in Western Australia. Expected production capacity is 2,500 metric tons of U_3O_8 and the facilities should be in operation by 1984/1985.[78]

To be included in the tabulation should be the quantities to be supplied by a planned joint uranium mining venture at Beverly in Southern Australia. It will be undertaken by Western Uranium and the Transoil Corporation with a capacity to produce 1,500 metric tons of uranium concentrates.

More recently, it was reported that Delhi International

(53.5%) and Vam Limited (46.5%) are investing \$52.2 million to exploit the Lake Way Deposit containing 4,000 metric tons of U_3O_8. Annual output would run at about 500 metric tons which speaks for a low life expectancy of only eight years for this mine.[79]

Minatome Australia, a French company, is expected to produce 400 metric tons of U_3O_8 (and 200 metric tons of molybenum) annually by 1985 from its Ben Lomond uranium deposit. This orebody is located about 30 miles west of Townsville in Queensland. Estimates have it that the orebody contains also 4,000 metric tons of U_3O_8.

There is also the Honeymoon deposit where the Mine Administration Proprietary Limited, a subsidiary of CSR, intends to have a mine on stream in the fall of 1981. Its expected output will be 110 metric tons of U_3O_8 which eventually will rise to 450 metric tons annually. It is located 45 miles northwest of the famous Broken Hill mining camp.[82]

Besides these outstanding uranium investment projects, two aspects, not directly connected to the mining of uranium ore, help enhance the marketability of Australia's uranium: one of these concerns the possible construction of a UF_6 enrichment plant. Presently, a feasibility study of \$570,000 for a modern gaseous centrifuge is under way. In this connection the South Australian Uranium Enrichment Committee has concluded a 'commercial confidentiality' agreement with

Ureno-Centec, a British-Dutch-West German consortium,to build such a plant at Port Pirie. Annual output would run at 250 metric tons of UF_6 using 1,500 metric tons of U_3O_8. These plans are going ahead even if strong labour groups in Australia are vehemently opposed to a uranium industry.[83]

The second aspect centers on the problem of safeguard guarantees to prevent proliferation of uranium substances most notably that of plutonium which could be used for 'non-peaceful' purposes. The Australia government has decided on a policy imposing less stringent conditions on the reprocessing of spent uranium for its customer countries than Canada and the United States. This move which provides for advance consent of a bi-lateral, case-by-case, agreement was immediately welcomed by France. Such agreements, it was quoted,were considered as contributing towards the successful exploration of a number of new mining projects including Jabiluko and Koongarra.

Two such agreements were concluded. One with the United Kingdom (1979) and the other with France in early 1981.[84] However, they were superceded by a summary agreement between Australia on the one side and Euratom, the nuclear arm of the ten members of the European Economic community, on the other. Sweden is also well on the way to follow the direction of the members of EEC. So far, Sweden has contracted to buy 2,858 metric tons of U_3O_8

from Australia between 1982 and 1996.

In this fashion Australia has taken steps to assure a market especially in Europe for its ever-increasing uranium supplies.

Canada	Uranium Production	1956:	2,068 metric tons
		1959:	14,414 metric tons
		1979:	8,136 metric tons

Although the Province of Ontario had been considered the main source of uranium through the Elliot Lake, Agnew Lake and the Bancroft operations, interest has now shifted back to developments in the Province of Saskatchewan. At Cluff Lake Saskatchewan, the Amok Corporation had plans to have a uranium mine in operation by 1981. The scheduled investment was $130 million with an initial output of 1,180 metric tons. Eventually, it could be raised to 1,800 metric tons; but, at present, indications are that even this new mine will have to work below basic capacity.[85]

The second of the important uranium projects under development in Saskatchewan is at Key Lake and it should be in operation in 1983. The cost will be $450 million and the expected output ranges between roughly 3,600 and 5,400 metric tons of U_3O_8. Formed in 1979 the Key Lake Mining Corporation is owned by the Saskatchewan Mining Development Corporation (SMDC, 50%). Uranerz Exploration and Mining (33.3%) and Eldorado Nuclear's Eldor Resources (16.7%)[86]. Unfortu-

nately, this development was suspended pending the results of an inquiry by the Province.[87]

Another significant addition to Canada's uranium capacity could come from ore discovered at Midwest Lake 16 miles west of Rabbit Lake. It is held by Esso Minerals of Canada and managed by Canada Wide Mines, a wholly owned subsidiary of Esso Resources Canada. A high-grade ore deposit is involved which could produce about 2,000 metric tons of U_3O_8 annually depending on early government approval and on market conditions. Construction had been planned to start in 1981.

Additional sources of uranium could be tapped were Gulf Minerals to start mining its Collins Bay 'B' deposit about 7 miles north of Rabbit Lake.

In the Province of Ontario, Denison Mines expects its capacity to more than double from 2.6 million tons of ore hauled to 5 million tons. This expansion program will be completed by 1985 adding roughly 2,000 metric tons of U_3O_8 to its existing capacity. The cost will be $250 million.

Rio Algom, the equally important neighbour of Denison Mines in Elliot Lake, has definite plans to come into effect by the year 1984. It intends to up-date the old Stanleigh Mine of Preston Mines chiefly through financing by Ontario Hydro.[88] The hope is to increase output by 907 metric tons annually at a cost of $200 million. Finally, it should

also be mentioned that Preston Mines which controlled the Stanleigh Mine, and Rio Algom officially have amalgamated as of January 30, 1980.[89]

From the negative point of view, Brinco's Brinex will not go ahead with the exploitation of its Kitts-Michelin project in eastern Labrador at the other end of the country, at least for the time being. This is mainly due to a poor uranium market, but also because the provincial government has withheld the developing license pending a satisfactory solution by the company of radioactive waste problems.[90]

In summary, investments actually under way and those in the planning stage and/or subject to government approval amount to a potential addition to Canada's uranium mining output of at least between 9,700 and 12,300 metric tons at an expenditure of over $1.4 billion. On the base of this information Canada's annual production volume could approximate very quickly a potential of about 17,880 to 20,400 metric tons of U_3O_8.[91]

Namibia

Uranium Production 1977: 2,758 metric tons
1979: 4,354 metric tons

Namibia's uranium (Table 3) comes from the world's largest open-pit uranium mine of the Rössing Mining Company owned 46.5% by Rio Tinto Zinc.[92] Unquestionably, any further

development of Namibia's uranium mining industry is related to the uncertain political future of this former German colony. At least five companies have interests in uranium mineralizations in Namibia but they are very reluctant to commit funds to the exploitation of these resources in a country pregnant with such a growing political risk problem!

One of these companies is the General Mining Corporation (Gencor) which has been evaluating the Langer Heinrich deposit to the south of the Rössing deposits near Tinkes in the Namib Desert Park. This ore is of an even higher grade than that of the Rössing mine and could, if opened up, deliver 1,500 tons of U_3O_8 per annum.[93]

Second, GFSA[94] has a mining property at Karibab (Trekkopje' deposit) north-east of the Rössing mine camp. Here, too, a favourable political situation would positively influence the development of this mineralization.

Third, north of this area, there are mining claims staked out by three companies. They are Anglovaal, Rand Mines and Falconbridge, companies with both liquidity and risk awareness and ready to wait for the solution of Namibia's political problems.

Four, and likewise to the north of the Rössing deposit, Tubas, a 'local' company, is reported to have encouraging results from bulk-sampling undertaken in France. However, development will be postponed especially since one of the

partners in this joint venture, the Anglo-American Corporation, "does not wish to invest in a new mining development prior to independence".[96] The other partners are the General Mining Corporation, Minatome and Omitaramines, a subsidiary of Elf Aquitaine.

In short, indications are that Namibias uranium production could be augmented dramatically. Yet, the political situation of this country will curtail the potential supply to the world market.

South Africa	Uranium Production	1956:	3,959 metric tons
		1979:	6,126 metric tons [97]
	Average Ore Grade	1978:	0.171 of one percent
		1979:	0.168 of one percent

Uranium falls under the South African Atomic Energy Act of 1967 for both South Africa and Namibia such that details on grade of the various deposits and on uranium exports remain secrets as the usual mysteriousness surrounds this nuclear fuel metal. Nonetheless, some basic information is available which is summarized in the following.

Uranium ore comes from four different types of mining operations:

1. as co- or by- product from gold mining;
2. as a by-product from copper mining;
3. as the main product and gold as a by-product,

and, 4. in the future, as a co-product of coal production.

The bulk of the output originates in the category of 'co- and by- product of gold operations'. More than 91 per-cent of South Africa's uranium has its source in twelve major mines. They and their outputs for the year 1979 have been presented in Table 6. This Table includes also the Palabora mine, the only producer of uranium as a by-product of copper production, the second category.

Two-thirds of South Africa's uranium are the results of normal extraction methods.[98] The remaining third, however, is derived from surface slimes and sand dumps - i.e. from tailings. Greatest interest evoked the Anglo-American Corporation when it formed ERGO (3) in 1977 with the purpose to extract uranium, gold and sulphur from 16 previously abandoned slime dams containing between 200 g/t to 500 g/t of uranium oxide and between 7.23 g/t and 15.48g/t of gold.[99] At an annual out-put of 12 million tons this enterprise could , it was thought, deliver a minimum of 2,400 metric tons of uranium and 84 metric tons of gold besides 6.36 million metric tons of sulforic acid (i.e. 5.52 million metric tons in excess of companies' needs). During the first eight months of operations ERGO produced 238.734 metric tons of uranium and 5.17 metric tons of gold,[100] which is substantially below expectations. Total capital costs had been $166.8 million.[101]

Another extraction project outside the conventional

Table 6

Uranium Production of South Africa

(Mainly as a by-product of gold mining)

By Major Mines and/or Groups for the Year 1979

Mine	Metric Tons (A)	Metric Tons (B)
1 Blyvooruitzicht	285.7	278.3
2 Buffelsfontein	620.4	663.9
3 East Rand Gold and Uranium (ERGO)	238.7	152.1
4 Harmony	540.9	527.1
5 Hartebeestfontein	394.2	383.3
6 Joint Metal Schedule (JMS)	676.3	678.1
7 Palabora (Cu-U)	(113.2)	113.2
8 Randfontein	413.0	406.9
9 Stillfontein	(271.2)	271.2
10 Vaal Reefs	1,273.4	1,358.5
11 West Drieffontein	288.3	280.7
12 West Rand Consolidated	367.5	401.0
13 Western Deep Levels	199.0	194.6
	5,297.4 (5,681.8)	5,708.9

Source: (A): 'South Africa, M.A.R., 1980, p. 493, Table: Breakdown of South African Gold and Uranium Production (Major Mines) in 1979;

(B): B.C.J. Lloyd, 'Uranium', M.A.R. 1980 p. 104; a difference of 27.1 metric tons of U_3O_8 exists between the values provided by the two series when summed on a mine by mine basis and if the values in (B) for #7 and #9 are added to (A) as indicated by the bracket.

mining operations is the Joint Metallurgical Scheme (JMS) put into effect by the same large corporation: the Anglo-American Corporation. Here, again, residual slimes from gold processing are being utilized in the extraction of uranium and gold. In this case,however, uranium comes from current operations of the corporation's gold mines in the Welkom area of the Orange Free State.[102] In 1979, JMS produced 676.262 metric tons of uranium and 1.95 metric tons of gold.[103]

With the uranium output of the second category stated in Table 6 and referred to above for the Palabora mine, the third type of uranium production in South Africa may now be dealt with. It involves the only mine of its kind where uranium is the primary produce and gold the by-product. It was in July 1978 that the Union Corporation of South Africa disclosed its plans to begin the Beisa Mining project at Welkom, S.A. The ore in question had a reported grade of 500g/t of uranium and 7.23g/t of gold.

This mine should be on stream in 1982 at a cost of $230 million ($240 million as to E. & MJ., August 1981, p. 145) million.[104,105]

Besides, there are another two mines which occasionally are included in this category. They are West Rand Consolidated and Afrikander Lease. This inclusion is a consequence of the relatively high uranium grades of these two mines.

The fourth category of uranium sources has been discovered only quite recently. In the Karoo area between the town of Beaufort West and Sutherland, exploration had been going on for several years involving mainly Esso Minerals, Johannesburg Consolidated Investment and Randfontein. Early reports spoke of widely disseminated, small and discontinuous uranium occurrences which could only be mined collectively. However, in the Springbok north Transvaal flats extensive coal deposits have been found in association with uranium in or near coal seams.[106] Uranium would be a co-product of mined coal if and when these reserves are being opened up.

Several other investments to expand uranium production are in progress in South Africa. There is the pressure leaching plant for processing uranium. It is being undertaken by Vaals Reef Exploration at Klerksdorp, Afrikander Lease. It is to produce 385 metric tons of uranium oxide at an original investment cost of $100 million.[107] Originally scheduled to start production in 1981, the new start-up date is the year 1982 [108] with $180 million cost including the rehabilitation of this old mine.

Harmony Gold has recently spent $36 million on a new uranium plant at Merrisspruit, while Randfontein which increased its output by 55% in 1980 is expanding operations in one area (the Cooke shaft to be ready in 1985) while its

sister mine, Western Areas, is working on the Elsburg reefs. It is interesting to note that part of the development cost comes from interest free 'consumer' loans repayable through uranium deliveries in 1983. Note also that Randfontein sells mainly to the French atomic energy authorities.[109]

Were one to include exploration expenditures, it should not come as a surprise that considerable sums are allocated for this purpose. Here, too, South Africa acts like all the other major uranium resource holding countries. A total of 26 companies spent about $25 million on uranium exploration in 1980.[110]

As to the marketing aspect, it had become customary by 1979/80 that all uranium producers of South Africa except the Palabora Mining Company (Phalabowra) sold their uranium via NUFCOR, the Nuclear Fuels Corporation. This is a consortium consisting of the Anglo-American Corporation, Anglo-Transvaal Finance Corporation, General Mining and Finance Corporation and Union Corporation.[111] However, it is the Chamber of Mines of South Africa which is in charge of actually marketing the products.

Normally, all uranium was exported. This situation will change slightly as South Africa will bring its first nuclear power station, Koeberg, on stream. Had South Africa joined the nuclear anti-proliferation treaties, then, it could rely on the United States to supply the

necessary enriched uranium fuel. But since South Africa is not a signatory to this international agreement, an embargo by the authorities in the United States has been placed on the exports of enriched uranium to South Africa. In this way South Africa was forced to develop its own enrichment facilities. The cost of this undertaking may be too high if South Africa is the only consumer of its enriched uranium.[112] With this point in mind the reader could conclude that South Africa may become a supplier of enriched uranium to other countries in the world!

In short, South Africa's uranium producers have committed over $450 million to the expansion of their operations, not counting annual exploration expenditures to raise output by about 1,000 metric tons annually. However, it should also be mentioned that the weakness of the uranium market as it developed in the early 1980s has forced South African uranium mines to reconsider their development plans and to proceed with extreme caution. For instance, West Rand Consolidated as well as other firms have already asked for state assistance.[113] Western Deep Levels is contemplating production cutbacks, while Harmony Gold will stockpile, at least, temporarily.[114] It has also been reported that uranium bearing slimes will be stockpiled pending improvements of world markets. This means that production of uranium will be highly responsive in the future to improvements in uranium

prices. This is especially true considering that uranium is not the main source of income of operations of most of these mines but serves the role of a cost-covering by-product in financing gold-mining operations. Weak uranium prices will not mean overall losses as could be for the 'pure' uranium mines but merely a loss of otherwise "welcome contributions to cash flow".[115]

A much greater flexibility marks the uranium industry of South Africa than is the case in most other countries because uranium mining is a possibility but not a 'must' in South Africa. This was demonstrated by the General Mining Union Corporation which has decided to terminate the production of U_3O_8 altogether at West Rand Consolidated (Table 6 (12)) to emphasize only gold production.[116]

Gabon

Uranium Production	1963:	528 metric tons
	1975:	800 metric tons
	1979:	1,100 metric tons

Gabon is the world's sixth largest uranium mining country working four deposits with a reserve of 31,750 metric tons of uranium. The ore grade of this reserve which is located close to Franceville ranges between 0.3 and 0.5 of one percent. It is therefore of a very high grade compared to the average grade of say South Africa whose ore were 0.171 (1978) and 0.168 (1979) of one percent.

Hindered by inadequate and bad road facilities

Gabon's production of uranium was 1,100 metric tons of U_3O_8 in the year 1979 60 percent of which was exported to France. Its production capacity should increase to 1,500 metric tons by the end of 1981. This means that the given reserves - which are the same for both long and short run periods (Table 5) - would sustain Gabon's contribution to the world market for about 20 to 25 years. By the year 2000, Gabon's supply capabilities would taper off unless, of course, new ore deposits are discovered in the meantime.

COMUF or the Compagnie des Mines d'Uranium de Franceville is the sole producer of uranium working at full capacity.[117] However, two industrial groups, Speichin S.A. (Empian Schneider Group) and Tecminemet S.A. (Imetal Group) are engaged in the construction of a plant to process uranium.[118] As for further mining of uranium KECO, the government-controlled utility company of South Korea, and Cogema of France have jointed to exploit a deposit in the Lordleyon region. This is the most recent development of uranium mining in Gabon.[119] In addition, exploration of uranium prospects continues and the government, in partnership with Cogema - PNC, has established significant uraniferous mineralizations in the N'Khan region. Further efforts by this exploration consortium will extend to Bakoué in the South.[120]

In brief, the impression one obtains from the activities in Gabon is that the uranium potential appears to be

more significant than has been conveyed by the estimates of Table 5. Consequently, 'speculative' reserves may already be under discovery such that Gabon's supply to world markets may exceed expectations and last probably longer than initially indicated.

Niger

Uranium Production 1971: 430 metric tons
1979: 3,891 metric tons

Niger is one of the world's poorest countries sitting land-locked in the west of Africa. Still, it disposes of a much larger uranium reserve than Gabon (Table 5). In the year 1968, the first uranium mining company was formed under the name of Société des Mines de l'Aïr (Somaïr)[121] which followed the discovery of the Arlit deposit in the Agadez Basin in the Region of Aïr by the Commissariate à l'Energie Atomique.

This deposit is 20 to 25 meters thick with a grade of 0.15 percent of uranium oxide. Its initial annual output capacity of 750 metric tons was raised to 1,500 metric tons in 1973; by 1982, it will have reached 2,300 metric tons annually.

In August of 1978, the Akouta mine was put into operation.[122] Discovered in 1966, it lies 12 miles from the first, the Arlit deposit and is exploited by Cominak, the Akouta Company. An underground mine is involved with a 0.4

percent uraniferous sandstone (magnesium uranite) relying on a reserve of 44,000 metric tons of contained uranium. At an annual output level of 2,200 metric tons it also produces about 450 tons of molybdenum per year as a by-product.

Niger's annual uranium capacity is expected to rise to 5,800 metric tons of uranium oxide by the end of 1983 through the output of a third mine. Located also in the Arlit area, this deposit was discovered in 1969 containing an ore reserve of 20,000 metric tons of uranium resulting from an ore-grade of 0.35 of one percent uranium oxide.[123]

A second prospect to raise Niger's output to between 8,300 and 8,800 metric tons of uranium has been postponed for the time being pending improvement of world market conditions. Found in 1967, this orebody lies at Imourarem and has a reserve of 70,000 metric tons of uranium with a relatively low grade of 0.12 of one percent uranium. It would require an underground mine for its exploitation due to an overburden of about 100 metres.[124] Four years would be required to have this mine operational.

By 1985, Niger's output could rise by another 2,000 metric tons of uranium to over 10,000 were the West Afasto mine to be opened up.[125] Containing 50,000 metric tons of uranium[126]-an ore-grade of 0.4 of one percent-and also located in the Air region this project has attracted the partnership of 32 utilities and mining companies.[127]

Three other mineralizations are under investigation. A consortium is studying an extension of the Madaouela deposit which was discovered as early as 1962/1964. It is close to the West Afasto orebody and runs under the name of Techili.[128] The second mineralization in this context south and close to the Imourarem area is under survey by an international consortium[129] while at the southern border with Nigeria another consortium of firms from the United States is exploring for uranium, with Onarem to become "an equal partner in a mine project."[130]

The known uranium mining potential of Niger is great by any standard of comparison and will be larger as other projects will be phased in during the decades to come. Of special interest are:a) the widespread uranium occurrences in this central part of North Africa with exploration activities taking place as far away in other countries as in the Ivory Coast, Algeria, and Nigeria in Niger's north and south respectively, and potential occurrences in Chad once political stability has returned to this troubled country; b) the point is that these countries are non-uranium consumers and, as such, will represent very strong competitors in the world markets possibly supplying Spain, France, Western Germany, the United Kingdom and Japan. Unquestionably, this competition will make itself felt especially to the Canadian uranium industry.

The United States

Uranium Production	1956:	5,442 metric tons
	1960:	16,108 metric tons
	1967:	8,278 metric tons
	1975:	8,900 metric tons
	1979:	16,961 metric tons

Structure in Review

The number of U.S. uranium producers and their variability over time in response to changes in uranium markets is very impressive by any standard of comparison. In 1960, the previous peak year of uranium output in the United States for the period under analysis, 965 producing mines were noted; they shrank in number to 263 in 1970 and by 1974, only 173 were operating of which 123 were underground mines, 31 open-pit mines and another 19 accounted for diverse uranium recovery operations such as heap and in-situ leaching. Evidently, market pressure led to this reduction especially since the Atomic Energy Commission had curtailed its procurements.[131]

The last of the two references described the market structure somewhat differently: when the weakness in the uranium consumption materialized, eventually, 400 mines were operated by 125 companies. But 150 mines were still worked by 110 small but independent producing companies accounting for less than 10 % of the total output. The remaining 90 percent were extracted by the other 250 mines owned by 15 companies which were, to a large degree, milling companies.

Understandably, some of the most important mining companies of the U.S.A. are also present in the uranium mining industry. They are, for instance, the Kerr-McGee Corporation, Anaconda, Utah International and Exxon Minerals, the most outstanding among the top twelve names in uranium mining.[132]

From the mining side of uranium the view crosses over to the uranium milling companies and their facilities. By 1975 standards, there were about 15 companies with top-names able to mill 28,500 metric tons of uranium ore daily, including again, of course, the same names of the biggest uranium companies.[133]

Proceeding to the processing and the production of uranium nuclear fuels another 20 companies were listed for the year 1974 with facilities distributed over 31 locations in the United States. Again, previously encountered names reappear on the list. Were one to go another step further, the manufacturers of reactors would come into focus marking the top of the vertical production structure from the uranium mine to the production of the capital equipment containing nuclear fuel. Westinghouse Electric could be a case in point as it has stretched its operations from the mining of uranium by its Wyoming Minerals Corporation to the production of reactors.

The point is that although the number of firms even

in the processing of fuels is quite substantial, the basic industrial structure of the uranium industry is of an oligopolistic variety with both features of vertical integration and a large fringe of competitive mining firms which account for all but ten percent of uranium mined. Yet, this small competitive fringe may play a larger role in the uranium market since these companies are free to sell to foreign purchasers who,in turn, contract with official firms for uranium enrichment. A great flexibility in the industry is assured through the relatively larger number of participants than appears to be the case in other countries.

This industry is able to expand quickly if demand requires expansion of production such that the total uranium output of the United States is bound to increase. Conversely, if conditions are unfavourable due to depressed markets the uranium mining industry is able to contract output quickly by shutdowns and cutbacks while investment mining projects are stopped whenever necessary even if only a step away from start-up of operations!

Consequently, competitive influences still permeate the United States uranium industry to a larger degree than in other countries, especially because the mere fear of anti-trust action seems to keep them from doing otherwise. Just to give an example of the presence of a considerable number of mining companies in one of the major uranium

mining camps of the United States, and not that of one or two companies only. It was recently mentioned that in northwest New Mexico, the most important uranium area of the United States, 20 companies are involved in 70 existing and potential uranium mines with an ore reserve of 374,000 metric tons of contained uranium oxide.[135]

Investment Activities

The U.S.A. uranium industry closed the year 1980 under the impression that about nine new uranium mining projects would be on stream between 1981 and 1984.

1. Amoco Minerals had planned an open-pit mine - the Hansen project - in Colorado to produce 4,100 metric tons of ore daily;
2. Conoco jointly with Wyoming Minerals had plans to start an underground mine at Crowpoint in New Mexico by 1982 to produce 1,300 metric tons of ore daily. This investment would have cost $240 million of which $35 million have been spent;
3. The Cotter Corporation had intended to start the first open-pit mine in Paradox Valley in Colorado as the C-J-D-7 project to produce 1,000 metric tons of ore daily;[136]
4. Philips Uranium was reported to have begun initial mine construction work in Rose Neck, New Mexico. An underground mine was planned to produce 737,000

metric tons of ore annually; and

5. The Tennessee Valley Authority had scheduled a mine in Morton Ranch Wyoming to extract 1,800 metric tons of ore daily by 1984. The United Nuclear Corporation was to manage the project.

By now, all five investment projects have been suspended due to weak market conditions.[137] However, some other projects have not been hit by such bad news. They are still in progress. There is,for instance,Anaconda's Rhode Ranch Mine in Texas with an expected annual ore output of 163,000 metric tons. It continues but the company had to place a $3.31 million performance bond for correct land reclamation on 300 acres of a 8,909 acre permit in McMullen County near Tilden.[138]

Conoco has filed for a permit late in 1980 to start an open-pit mine by 1983 in the famous Pumpkin Butte Area of Wyoming to produce 2,700 metric tons of ore daily. The amount to be invested remains undisclosed,at least, at the source consulted.

The biggest project of them all appears to be an underground mine of Gulf Mineral Resources, one of the giants in the field. $500 million are earmarked to deliver 3,800 metric tons of ore daily in 1984.

Homestake Mining's $6 million investment in LaSal, Utah, is comparatively small against the other projects.

It is to produce 400 metric tons of ore daily and should be on stream already in 1981.

Furthermore, Union Energy and Mining in association with Power Resources is proceeding with the first in-situ solution mine in Colorado.[139] In addition, two other uranium projects continue: one is being undertaken at Slick Rock in Colorado in a joint venture by Pioneer and Uravan. It is to be on stream in 1982 to treat 700 to 1000 metric tons of ore daily[140]; the other is being constructed by Union Oil through Mineral Exploration Company in the Rawlins area of Wyoming at a cost of $45 million.[141]

These are, no doubt, substantial development projects although their impact on future output will only become visible after the uranium market is out of its doldrums. This is so because the year 1981 is marked not only by suspensions of new mining projects but also by extensive cutbacks and shutdowns of existing uranium mining operations. For instance, United Nuclear Corporation closed down three small mines in the Ambrosia Lake area in New Mexico[142]; so were two open-pit mines of Kerr-McGee Nuclear in the South Powder River Basin of Wyoming. Poor market conditions also forced the closure of Wyoming Mineral's Irigaray in-situ solution mine near Buffalo, Wyoming,[143] while Homestake Mining, after the long-awaited final approval by environmentalist groups has given up the idea to go ahead

with its pitch-uranium project in Colorado, at least for the time being.[144]

The Cotter Corporation has laid off 75 out of 200 workers at its uranium-vanadium plant in Canon City, Colarado reducing output by 58 percent. At the same time the Cotter Corporation has terminated all contracts with mine operators which supplied uranium to Cotter; only its own Schartzwälder underground mine remains in operation.[145]

Uravan is closing four of its five small mines on the Colorado Plateau,[146] while Western Nuclear has abandoned though temporarily only, the Congo Mine development in Wyoming - it had been blocked by environmental considerations - .In short, so far in the State of Wyoming 1,800 uranium miners have been laid off since February 1980.[147] This number includes the 244 men laid off by Western Nuclear which has cut production in 1981 down to 44.8 percent from 1980 output levels.

What more could express the uncertain nature of the uranium market as the reduced long-term capital outlays and the short-run cutbacks of this industry which in the United States seems to respond quickly to market pressures?!

Other Countries

Following the summary statistics of the Engineering and Mining Journal, January 1981, a number of uranium pro-

ducing countries of somewhat minor importance are involved in investment activities expanding their uranium capacities. Countries to be mentioned are: Argentina, France, Sweden, Yugoslavia, Mexico and India.

Argentina

In Argentina, Comision Nacional Energia Atomica (CNEA) will go ahead and invest $150 million to produce and mill 700 metric tons of U_3O_8 at Suerra Mendoza Province. Production will start in 1983 and is to be raised to 7,000 metric tons of uranium oxide within 15 years.[148] Argentina is known to have 50,000 metric tons of uranium reserves and presently produces more than reactor Atucha I uses and the Cordoba reactor will use when in operation. Argentina is exporting 240 tons of uranium oxide to Brazil annually.[149]

France

In France, Cogema and APC are building a tailings retreatment plant utilizing phosphoric acid from APC to produce 100 metric tons of U_cO_8 annually starting in 1981.

Sweden

In Sweden LKAB has proposed to construct an underground mine at Arjeplog to extract 300 metric tons of uranium per annum; a permit has to be obtained to start actual construction.

Yugoslavia

Yugoslavia presently is engaged in two endeavours concerning uranium. One deals with a mine plant at Ljubljana where $40 million are being invested to secure an output of 272 metric tons of U_3O_8 annually. The Fluor Corporation has the contract and this plant should be already in operation.[150] The second development project will cost $31 million for the recovery of uranium from phosphoric acid at Prahavo. The expected production volume will be 100 metric tons of U_3O_8 per annum.

Mexico

Mexico is expanding its exploration of uranium since it intends to raise its nuclear energy capacity from 1250 Mw in 1983 to 20,000 Mw by the year 2000. Insufficient uranium discoveries has led Uramex to survey 424,700 square miles of which 1.81 percent carry potential uranium mineralization. Estimates have it that 222 metric tons of U_3O_8 could be extracted by 1982 and 544 by 1985 from an ore reserve of 15,000 metric tons. Interestingly enough,Canada has a considerable stake in the second nuclear reactor to be built in Mexico in the future. Arguments are flying high because the first Mexican reactor, Laguna Verde, uses enriched uranium for fuel, while the second would just feed on natural uranium should Canada's CANDU reactor be adopted. Such an event

has been interpreted already as a mixing of two different technologies leading to alleged inefficiencies. The strongest arguments originate from France with which Canada seems to be in competition over this issue.[151]

India

Another country with very ambitious projects and intentions is India. Proposals for three mines and two mills have been made on top of a proposal of a mine and mill expansion complex at the Jaduguda site. This mine has a capacity to mill 1,000 metric tons of ore per day. Retreatment of tailings of the Hindustan Copper Corporation are also under consideration at Rakha and Mosabani, all in Bihar State after test runs have been carried out successfully.

India has potential uranium reserves of 67,343 metric tons of U_3O_8, a figure which could even be larger.[152]

SECTION V: THE FUTURE OF URANIUM PRICES, PRODUCTION AND CONSUMPTION

Prices

Historical Uranium Prices

The general mysteriousness surrounding the world uranium scene holds true for the exact price quotations for the metal as well because there is no open market. In addition, technical circumstances peculiar to uranium only such as forward purchase agreements with possible delivery dates contracted for three decades ahead of time produce an atmosphere of greater uncertainty for the price determination of uranium than is customary for all the other metals under study. Considering also that uranium operations have been and remain under the watchful eye of governments, especially, in the United States and that various governments entered into cartel arrangements only testify to the difficulties in determining a price with even a slight resemblance of a market price. This is so because there is no market in the first place. Phone your broker and try!

An apparent lack of willingness to divulge the magnitude of daily transactions at the various prices is reflected in the conflicting and confusing reports issued on the so-called time-price relationships. For instance, the U.S.B.M. in a specific series presents a part in terms of average purchase prices of the Atomic Energy Commission of the United States on a fiscal year basis, while the second part (1970-1974) lists

the estimated average private market price for purchases and delivery during the year. In another publication the same Bureau refers to prices quoted in the Engineering and Mining Journal. This type of stating of prices is very disconcerting for the economist especially as it is unconceivable that in the so-called free market system the average price 'averaged out' at the same value of \$8/lb U_3O_8 for the years 1964 to 1968 as shown in Table 7. This is the official average purchase price in that partial series.

Consequently, a separate series had to be assembled which was based on a mixture of different price notations gleaned from official U.S. and Canadian price statistics with adjustments made for the annual average exchange rates at which the currencies between these two countries traded in the various years and for other basic cost differences of uranium prices in the two countries. The result was the complete price series in Table 7, (left column) with the quotations for the more recent years obtained as the annual average from the monthly quotations provided by the Engineering and Mining Journal.

Furthermore, nominal United States dollars were used as value scale instead of constant 1979 \$US as has been the case so far in this study with all other metals. The reason is simply that the econometric analysis performed best when nominal dollars were entered as cost factors did not seem

Table 7

Uranium Prices in Nominal $US per Pound of U_3O_8

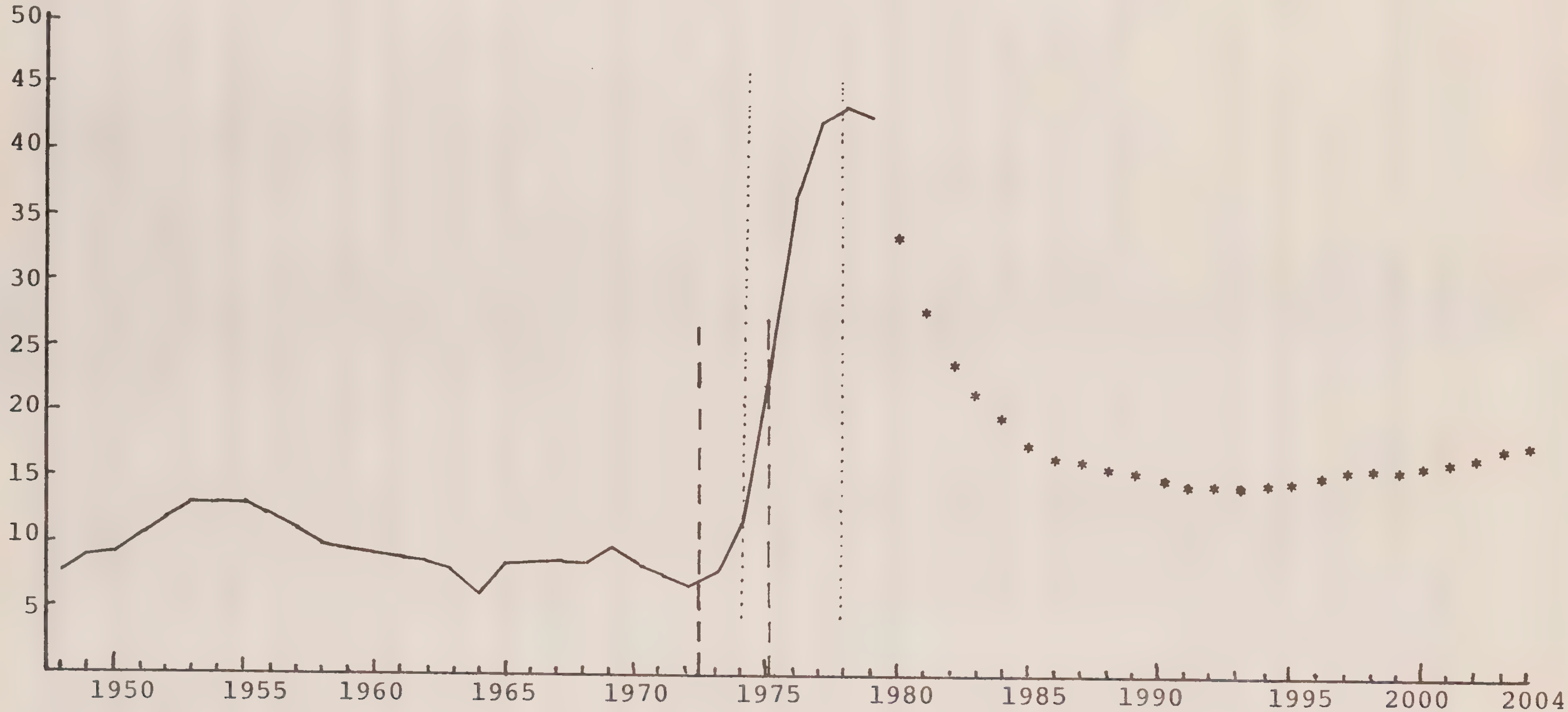
For the Years 1948 to 1979

Year	Main Series $US/lb	U.S.B.M.* $US/lb
1948	7.14	
1949	8.53	
1950	8.92	
1951	10.01	
1952	11.19	
1953	12.30	
1954	12.25	12.27
1955	12.51	12.25
1956	11.63	11.51
1957	10.53	10.49
1958	9.57	9.45
1959	9.25	9.12
1960	8.99	8.75
1961	8.54	8.50
1962	8.20	8.15
1963	7.85	7.82
1964	5.97	8.00
1965	7.25	8.00
1966	7.14	8.00
1967	7.33	8.00
1968	7.30	8.00
1969	8.35	6.99
1970	7.41	6.30
1971	6.48	6.20
1972	5.95	6.30
1973	6.41	6.50
1974	11.45	10.50
1975	23.68	
1976	36.28	
1977	42.20	
1978	43.28	
1979	42.57	

*Source: see Woodmansee, loc. cit.,p. 1192, Table 10.

Exhibit 1

Historical Prices (solid line) and Projected Prices (**********) Of Uranium (U_3O_8) in Nominal United States Dollars per Pound For the Years 1948 to 1979 and from 1980 to 2004 respectively



to have any comparable bearing on the explanation of economic relationships underlying uranium prices, consumption and production. This means that other factors cast a much bigger 'spell' on uranium than the cost of producing the mineral! However, this explanation is not to be interpreted that costs are or will be unimportant to the industry but rather that those other factors reduce the statistical significance in general. However, it has also to be recognized that under conditions of weak markets cost will eventually exercise their rationing fuction by setting the lower limit below which output cannot be expected to be forthcoming.

It is interesting to observe that the first height of uranium prices occurred in the period of 1954/55. From $7.14/lb in 1948 uranium prices climbed to between $12.25/lb and $12.51/lb and it was with a clear lag of several years (Table 2 and 4) that output rose dramatically in the Western World. This may be seen especially in the United States and in Canada with 1960 as the peak year of uranium production. By then, the price of uranium had been eroded as it fell below $9/lb standing at averages of $8.99/lb and $8.54/lb for the years 1960 and 1961 respectively.

Exhibit 1 demonstrates the price movement. While uranium prices were gently sliding to lower levels, the lag was shorter on the downside and output of the world, in the United States and in Canada decreased rather quickly during the period from

1961 to 1965. However prices and output remained stable at these low levels with the bottom noticeable for both series in the years 1971 and 1972. Note also that in these years uranium producers were unable to sell their products even at prices much below the annual quoted averages.[154] It was observed that, for instance, Denison Mines lost a bid at $3.95/lb and late in 1971 some sales had actually been transacted, reportedly, below the $4/lb-mark.[155]

By the middle of 1972 the now famous uranium cartel had sprung into action; it lasted until early 1975. This period has been shown in Exhibit 1 by two dashed vertical lines. The effect of this coordinated market price mechanism saw a phenomenol rise above all previously recorded heights of uranium prices starting in 1974 and lasting until 1978. A dotted vertical line in the graph delineates this period of time as the explicitly set cartel period 1974 to 1978 used in the econometric analysis during which repercussions of higher uranium prices were most severely felt .

Specifically, annual average prices for uranium were $11.45/lb in 1974 only to run away to a top annual average of $43.28/lb in 1978. The year 1979 signaled the beginning of the eventual reversal of this extraordinary price performance as the uranium producers of the world and, especially, of the United States responded to this price signal most likely mistaking it for a normal market indication of rising

demand which truly and temporarily had risen drastically under the scare-cry of imminent and long-lasting world-wide shortages of the metal.

Future Prices

The price projection of the econometric analysis is presently born out by reality. A dramatic decline in these prices is in the offing as shown in Table 8 and illustrated independently in Exhibit 2 and in continuation of historical prices in Exhibit 1 where it takes the form of little asterisks. At the time of writing, the average monthly price for August and September 1981 has been $23.50/lb.[156] The overall projection, therefore, is for a substantial decline of (nominal) uranium prices through the 1980s with the bottom foreseen to occur in the early 1990s ($14.76/lb). By 1994 a new upward trend will begin resembling the market behaviour of pre-cartel times and reflecting the expanded uranium fuel consumption needs brought about by a larger number of reactors. By the year 2000 uranium is to cost slightly more than $16/lb and four years later it could be close to $18/lb if one could see so far into the future.

Future Uranium Production

The future output of uranium in the non-communist world is presented in Table 8 and set out in Exhibit 3. According to the econometric forecast and subject to the repeatedly

Exhibit 2

Uranium Prices in Nominal US Dollars Per Pount of U_3O_8

For the Years 1980 to 2004

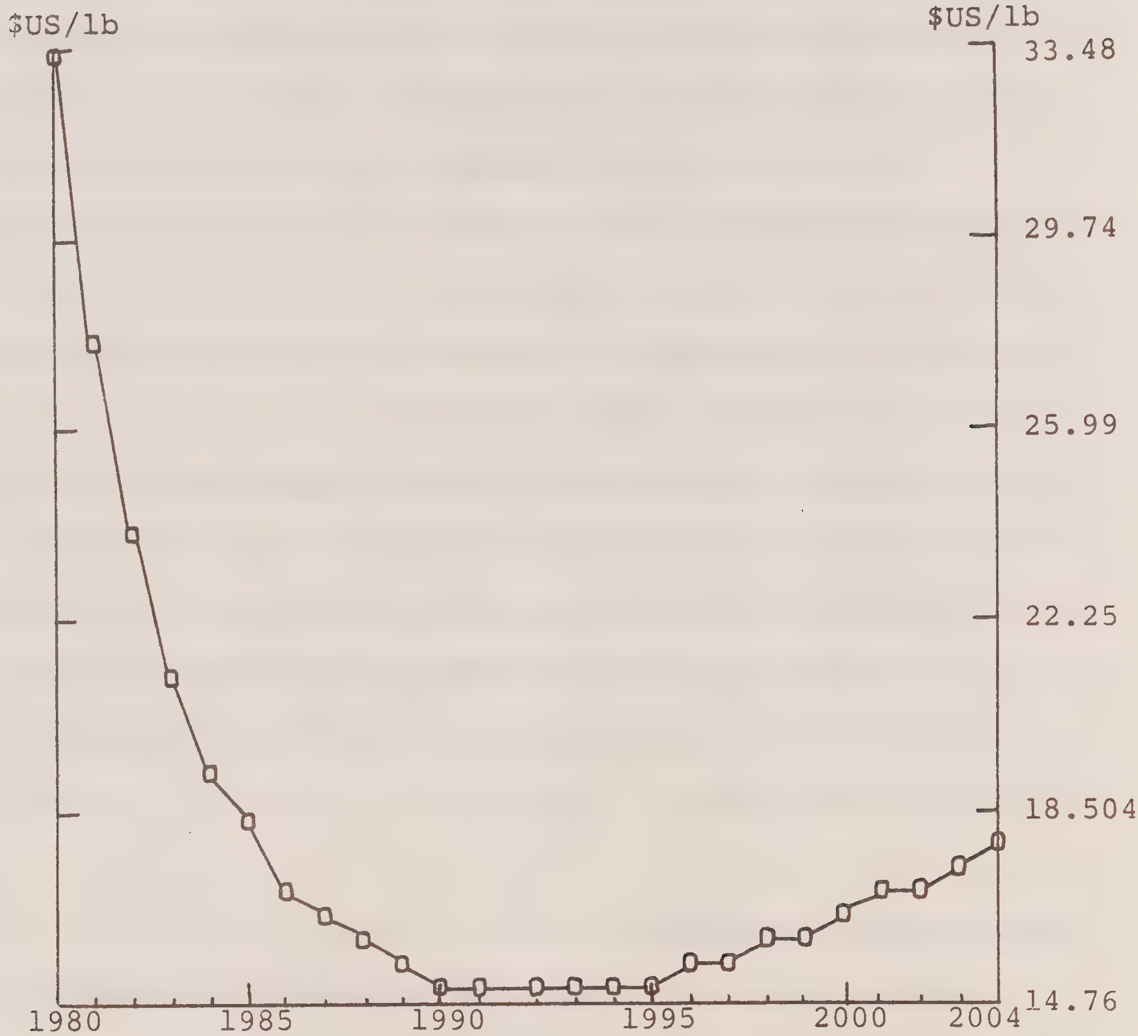


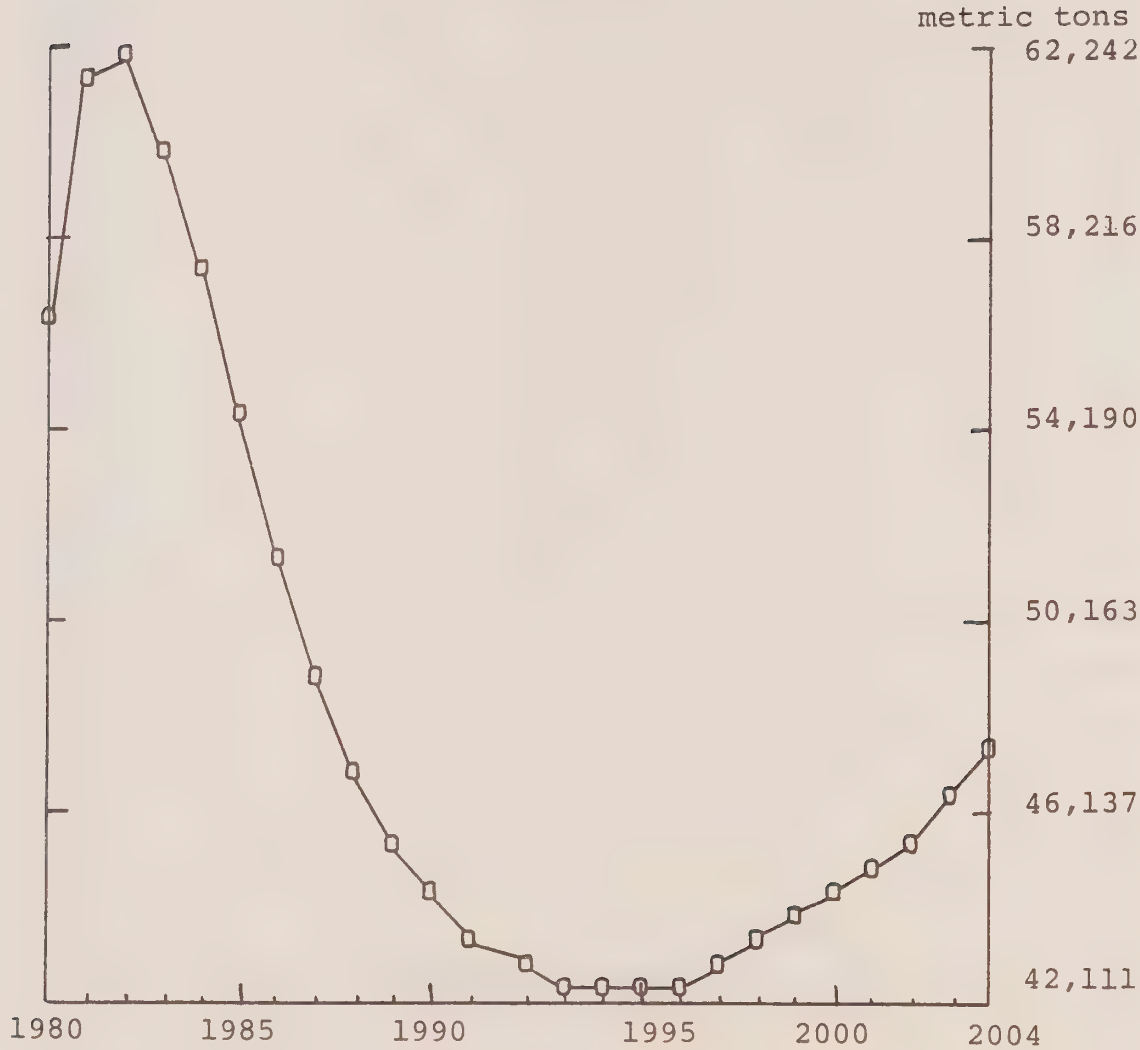
Table 8
Uranium Prices in Nominal United States Dollars per Pound
And World Mine Production in Metric Tons
For the Years 1980 to 2004

Year	$US/lb	World Mine Production Metric Tons
1980	33.48	56547
1981	27.71	61697
1982	23.86	62242
1983	21.19	60299
1984	19.28	57362
1985	17.89	54272
1986	16.88	51431
1987	16.13	48994
1988	15.60	46995
1989	15.22	45409
1990	14.97	44193
1991	14.83	43298
1992	14.76	42680
1993	14.77	42297
1994	14.84	42117
1995	14.97	42111
1996	15.13	42255
1997	15.34	42530
1998	15.59	42920
1999	15.87	43412
2000	16.18	43996
2001	16.51	44662
2002	16.88	45402
2003	17.27	46211
2004	17.68	47083

Exhibit 3

Western World Uranium Mining Output

For the Years 1980 to 2004



stated reservations as to the validity of such long-range predictions, uranium (U_3O_8) output will rise to 56,547 metric tons in 1980 from 44,977 metric tons actually recorded (and 55,117 of true simulated values)[157]. By 1981 uranium production will have reached a peak of 61,697 metric tons. For the following year, a deceleration is indicated by a relatively small annual increase of only 545 metric tons to 62,242 metric tons. In reality, this may turn out to be an actual decline occurring as early as 1982.

Hence, annual uranium output will decline quickly at first, and by the year 1990 the level may have dropped by about 2,000 metric tons or 30 percent below peak performance levels. This means that during the 1980s and the early 1990s the uranium supply will remain depressed, and it will only be in 1996 that an increase in output should materialize. This implies a lag of about four years after the price of uranium reversed its downward trend in 1992. In the late 1990s output will be 42,920 metric tons (1998) and with the beginning of the 21st Centruy uranium production will again reach 44,000 metric tons. At the end of the forecast period annual production is computed to be about 47,100 metric tons as output seems, then, to rise at an increasing rate. Beyond this date, if not already before, other factors will influence developments in the nuclear industry.

Cumulatively, the following totals were obtained:

Year	Cumulative Extraction of U_3O_8
1985	352,419
1990	589,441
1995	803,044
2000	1,018,157
2004	1,201,515

By 1985 about 352,500 metric tons of uranium will have been taken from the ground. Five years later, the total would come close to 600,000 metric tons reaching over 800,000 metric tons in 1995. The cumulative exploitation of uranium would stand at one million metric tons in the year 2000 and at 1.2 million four years later.

Future Uranium Consumption

Since no satisfactory time series for the annual industrial consumption of uranium has been easily accessible no consumption forecast has been attempted in this study. Instead an outside prediction has been utilized to fill this gap: a NUEXCO time series.[158] Unfortunately, though quite understandably, only the period from 1980 to 1990 has been given for the projection of consumption. Naturally, this period is much more important and more easily assessed than the years beyond that point in time because uncertainty clouds the future progressively.

At the same time, the production forecast by NUEXCO has served the purpose of a comparison between the results of this study. Table 9 presents the respective values while Exhibit 4

Table 9

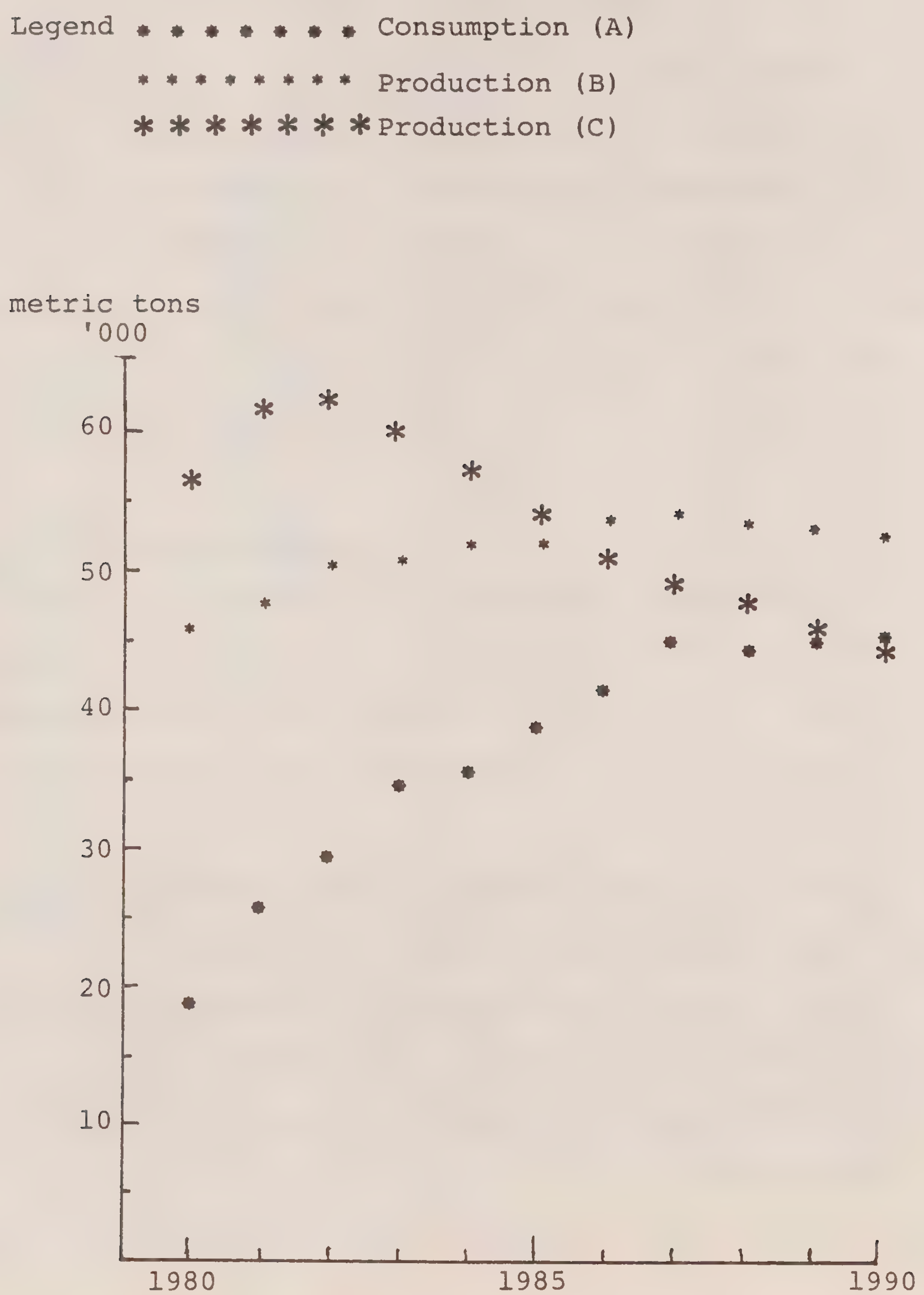
Forecast of Annual World Consumption, Production and Capacity to Mine Uranium (U_3O_8) For the Years 1980 to 1990 in Metric Tons (Western World Only)

Year	Consumption (A)	Production (B)	Production (C)	Mining Capacity (D)
1980	18,322	45,442	56,547	59,000
1981	25.488	47,256	61,697	
1982	28,934	50,612	62,242	
1983	34,104	50,929	60,299	
1984	35,102	51,791	57,362	
1985	38,730	51,791	54,272	109,400
1986	41,270	53,515	51,431	
1987	44,535	53,832	48,994	
1988	43,900	53,287	46,995	
1989	44,354	53,015	45,409	
1990	44,353	52,925	44,193	140,900
1995				145,100
2000				135,000
2005				110,900

Source: (A) and (B): George White Jr. "Supply-Demand Imbalance leads to sharp Price Break and Interest Seller Competition", Engineering and Mining Journal, March 1981, p. 143, Table 5; (C) The econometric analysis for this study; and (D) R.E. Green and R.M. Williams, Nuclear Energy - One Road to Self-Sufficiency, Atomic Energy of Canada Limited, April 1980, 94th Annual Congress, Engineering Institute of Canada, Calgary, April 23-25 1980, p. 9 in ref. to sources: NEA/IAEA 1979 December INFCE Working Group 1, 1980 January; figures for 1995 to 2005 from United States Department of Energy estimate ibid.

Exhibit 4

Projected Consumption and Production of Uranium (U_3O_8) In the Non-Communist World for the Years 1980 to 1990.



Source: Table 9.

demonstrates expected consumption and output behaviours until the year 1990.

In 1980 consumption of uranium fuel-that means the real burn-up-was 18,322 metric tons of uranium U_3O_8. The NUEXCO production figure for that year was reported at 45,442 metric tons while this study predicted a total output of 56,547 metric tons. According to the statistics published by ABMS. Non-Ferrous Metal Data, 1980 the actual figure was closer to 49,575 metric tons after some minor adjustment.[159] This means that actual estimated output was between the two figures of projected production (B) and (C).

Future consumption of uranium will rise at a decreasing rate and flatten out at 44,353 metric tons by 1990, as illustrated in Exhibit 4.

The output projected by NUEXCO will have exceeded projected annual consumption by 27,120 metric tons in 1980 meaning an addition to existing world inventories of 114,331 metric tons[160] at the end of 1979. The rate of annual inventory accumulation will decrease to 8,572 metric tons in 1990.

The results of this study, column (C), will exceed initially the projected value of projected consumption even more substantially than in series (B); but from 1986 on the rate of additions to stocks will be 10, 161 metric tons which is less than the 12,245 excess provided by the other production forecast(B). Reductions in output will become more severe

in the following years and, by 1990, this study envisages for the first time that the Western world would produce annually as much as it consumes. In the following years, a demand and supply balance could materialize on the basis of the underlying theory. Beyond 1990, it is quite conceivable that consumption will increase as well; but for a while the world uranium users can safely rely on substantial inventories.

Maximum Mining Capacity

The Nuclear Energy Agency and the International Atomic Energy Agency published a paper on the results obtained by the International Nuclear Fuel Cycle Evaluation Working Group (INFCE) with respect to the maximum production capacities of world uranium mines. While the summary findings have been placed into Table A4 - translated into U_3O_8 - the findings of relevancy at this point have been included in Table 9. Accordingly, the world's mining capacity in 1980 had been estimated at a figure amounting to 59,100 metric tons of Uranium U_3O_8; by 1985, it will be 109,000 metric tons and by 1990 annual output could be raised to 140,099 metric tons. Maximum annual output could be 145,100 metric tons in 1995 and 135,000 metric tons in 2000 while 110,900 metric tons could be extracted five years later, thus displaying a declining output trend provided, of course, that these possible maxima will have been reached.

With respect to the quantity of uranium consumed it is clear that the annual maximum capacity to produce uranium remains three times larger than the basic amounts required for consumption as fuels. Consequently, output in the 1980s will be closer to those capacity limits than later in the forecast period, but as the uranium mining industry is forced already now to gear down its operations well below its physical capabilities excesses of possible maximum production over actual output will be saved for future uses. This means that the underutilization (below maximum) predicted by this study - and to some degree by the NUEXCO forecast - will stretch the available uranium resources further into the future and the time horizon of a preditable shortfall of uranium supplies from reasonably assured resources - in the short-run sense of reserves - will be advanced farther away into the 21st Century. If one were to accept uncritically the predictions of this analysis for the end of this century capacity utilization of uranium resources would drop to roughly one third of what has been indicated by INFCE.

SUMMARY AND CONCLUSIONS

The discovery of a specific physical particle, the neutron, ushered in the atomic era when men finally succeeded in splitting atoms. The way of this technological change of unprecedented proportions led from the explosion of atomic bombs to the peaceful harnessing of atomic power by generating electricity.

There are three fissile substances: uranium 233, uranium 235 and plutonium 239, but only U 235 occurs 'freely' in natural uranium; U 233 and Pu 239 have to be created through neutron bombardments of Th 232 and U 238 respectively.

There are two types of nuclear reactors: the conventional, once-through, converter reactors which utilize the only existing U 235 in natural uranium, and disregard the recycling of potential fissile by-products. These conventional reactors use mainly light or heavy water as moderators and are labelled accordingly light or heavy water reactors. Canada has engineered the CANDU reactor which is unique in the world working with heavy water. The majority of reactors in the United States are light water reactors.

Besides conventional reactors, advanced technology has opened the doors for a whole family of advanced fuel cycle reactors generally called 'breeders'. Their purpose is not only to generate electricity but also to create new fissile

material during the burn-up. In this fashion the fuel available for reactors will be doubled as twice as much new fuel is produced than was consumed.

Breeder reactors are already in operation in the most important industrial countries, above all in the United States, the Soviet Union, the United Kingdom and France. Most of these have opted for the fast uranium-plutonium breeder although the slow thorium-uranium process has been put on stream in a few reactors in the United States. Since Canada has not officially decided to embark upon the application of breeder technology and since it will take about 20 years from design to commercial operations, this country cannot be expected to benefit from advanced fuel cycle technology before the turn of this century. In the meantime, Canada will use up its natural uranium foregoing both the recycling of the waste products and the more efficient fuel consumption of the thorium reactor.

In light of geological probabilities the occurrence of thorium in the world is at least three times greater than that of natural uranium. Thus uranium and thorium breeders would contribute to extending the life-expectancy of the world's nuclear fuel resources indefinitely into the future while simultaneously delivering more and cheaper electricity.

Uranium provides services in three general ways: in

reactors, in weapons and in other uses. In order to establish a consumption picture for the world and its countries, it would be necessary to know exactly the quantities used by at least the first two types of applications.

Since no country engaged in such 'defense' activities will divulge the size of its military stockpiles nor annual additions thereto, a big blank exists in this area of consumption measurement. In addition, a number of other unascertainable aspects related to the determination of inventories and to the lead time required for the processing of fuels cloud a precise assessment of consumption of uranium in the world. The 'other uses' appear too small to significantly affect the overall picture especially since one of these 'other uses' concerned purified, spent uranium. It absorbs but one tenth of burnt-up uranium and is much too small to influence the demand of uranium at all. It is just a by-product. Consequently, only a vague relationship exists between uranium consumption and the demand for mined uranium.

As no other metal, uranium has undergone a twenty-year world productive cycle displaying an extraordinary vulnerability to changes in the 'uranium market'. It is only in recent years that uranium has caught up with output levels achieved in the late 1950s. At that time, military absorption was the main reason for production while

demand for reactor fuel was still in its infancy. After military requirements had been met the industry had to perform at substantially reduced levels. This lasted until fuel needs of uranium reactors were large enough to support larger and continuously rising output volumes.

Canada's uranium industry displayed an even greater vulnerability as 5-year averages fell by 32 percent over the entire period while world output had but marginally declined. In the year 1957 the Province of Ontario had become an outstanding producer of uranium in the world but its relative importance shrank from 30 percent at the beginning of the period to about eleven percent by the end of the 1970s.

The United States as the world's largest uranium mining country reduced its output at a much slower rate than other countries; tnus, Canada carried the biggest burden of them all. Nonetheless, Canada was still the second largest uranium mining country in 1979 followed by South Africa, Namibia, Niger, France and Gabon with Australia making strong inroads to displace Gabon from seventh position.

At first Canada exported most of its uranium to the United States and later started to sell the metal to the United Kingdom which was to become our most reliable customer. Eventually, the United States cut back on the imports of uranium from Canada and slowly but surely Canadian ura-

nium exports receipts dwindled away from a high of \$Can 311 million in 1959 to \$Can 17.7 million in 1971.

The interesting observation was made that,at one time, the United States raised its domestic uranium output while Canada's 'taxpayers' paid the price as the Canadian government commenced stockpiling operations to keep this important industry alive.

By 1972 an international marketing arrangement by private firms in partial cooperation with governments - called the cartel - tried to stabilize and improve uranium prices. The United States had been explicitly excluded from this arrangement although some U.S. firms fell under suspicion of being in violation of anti-trust laws. A variety law and treble damage suits followed which have not all been solved yet!

After 1972 values of Canadian uranium exports rose to a somewhat higher level but it was only in 1978/1979 that a new peak was reached. By the middle of 1981 uranium receipts had virtually collapsed except that the U.S.S.R. was added on to the list of Canadian uranium customers.

The short and long run reserves of uranium in the world are 2.19 million and 5.93 million metric tons of U_3O_8 respectively while the secular total resources for the Western World lie in the range between 13.7 and 25.7 million metric tons.

The United States is the greatest holder of reserves in both the short and long run. From the short-run point of view the rank of the main reserve holder are b: Australia, South Africa, Canada, Niger, Namibia, Brazil, France; in the long run sense, Canada places second and the combined reserves of Canada and the United States amount to over 56% of the total of the Western World.

In the area of investment and potential uranium developments it can fairly be said that Australia is aggressively adding a maximum potential of 15,900 metric tons annually to its capacity to mine U_3O_8. This would bring output levels up to about 17,00 metric tons. At the same time, its reserves would face depletion in about 25 years.

Canada may increase its annual capacity by between 9,700 and 12,300 metric tons to a total of between roughly 17,00 and 20,000 metric tons. Operating at such a capacity would lead to a relatively swift exhaustion of the short-run reserves in this country. However, Canada can bank on its huge long-run reserves.

Namibia has additional high-grade reserves and could expand production beyond what has been recorded in Table A4 provided there would be an end to the political crisis.

South Africa is the most flexible of all uranium producing countries. Since the gold reserves are expected to last at least 50 years South Africa will be able to produce

uranium as a by-product over that time span. Moreover, other supplies will come from copper and coal where uranium is a co-product. During periods of weak markets South Africa can cut back drastically only to gear up quickly upon bright market news.

Gabon will be able to raise its capacity only slightly and its resources are so small that substantial output of uranium cannot last much beyond the beginning of the 21st century given maximum utilization of ore reserves.

With numerous significant uranium deposits held by important interest groups, Niger could raise its uranium mining output to well above 10,000 metric tons annually by the middle of the 1980s. It stands to reason that such a vast country may have even vaster reserves than anticipated. The possibility for uranium to occur in countries of North and Central Africa cannot be discarded as several of them are keen to join the uranium producing countries. Truly, most of them may not be immediate consumers of uranium in the next 25 years but they will obviously be strongly competing in the export market.

The United States is both the largest consumer and the largest producer of uranium, the latter thanks to its immense uranium reserves. Its uranium mining industry is very responsive to changes in uranium market conditions adjusting quickly to the short-run utilization of

its capacity by stopping current operations and by almost instanteously rearranging investment schedules and capital projects. Its industry is characterized by an oligopolistic market structure with features of vertical integration as well as a substantial fringe of a large number of independent uranium mines.

Other important countries including those mentioned in footnote 152 are eagerly trying to open up their uranium deposits with the view to either exporting the fuel mineral or to consume uranium domestically. The effects of these endeavours will certainly be carried over into the next century and should be felt by other competitors.

In the 'so called' uranium market there are uranium suppliers and consuming utilities negotiating contracts with delivery dates reaching up to 45 years into the future. These transactions are taking place under the watchful eye of governmental authorities to assure that rules of secrecy, security, and safeguards are readily complied with. Thus prices are not determined in an open uranium commodity market but in an exclusive and institutionalized trading area shutting out risk-seaking traders and speculators.

Therefore, uranium values may reflect imperfect market conditions. Prices rose to the middle of the 1950s only to decline slowly and steadily until the year 1972. Hence, they started to climb and a dramatic jump took place in

1978; afterwards they levelled off. Depressed prices are forecast until 1994 when slow improvements are foreseen by the econometric analysis, always provided one is willing to accept a prediction over such a long period of time.

After a brief rise world output of uranium will face an initially severe decline followed by a lengthy period of significantly reduced but stable production levels. A rising trend is projected to start only in the middle of the 1990s. Between 1980 and 2000 (2004) one million metric tons (1.2 million for the year 2004) will have been cumulatively mined. When predicted outputs during the decade of the 1980s are compared to consumption predicted by NUEXCO world inventories will rise until 1990 when a theoretical balance may be achieved between the quantities consumed by utilities and those supplied by the mines.

As capacities to exploit uranium deposits seem to be utilized to about one third, at worst, of what could be the maximum possible, the horizon of eventual 'depletion' will be pushed further into the future.

The following conclusion may therefore be drawn for the Canadian uranium scene.

In the short-run, the uranium producing companies with forward contracts will continue production while new ventures will be forced to operate much below planned capacity unless they are able to benefit from higher sales than

expected due to sales to foreign countries as a result of the favourable foreign ownership connections. They might be able to deliver uranium to consumers in France, the United Kingdom, Germany and Japan, to name a few.

In the 1990s the Canadian uranium producers may finally reap the benefits from investments undertaken in the early 1980s. Subsequent improvements in world market conditions will readily be filled by existing underutilized capacity. It does not seem plausible to contemplate expansion of uranium mining in this country now as other countries are seriously working towards a reduction of present and future dependencies on imported uranium from other countries. In the same sense, ores of poorer grade will have to wait until the high-grade ores in Western Canada have been exhausted.

At the turn of the century one million metric tons of the short-run uranium supply of the world will have been mined out, which is less than half the presently available reserves. If annual production were for some unexplicable reason twice as high such that this production forecast would have meant an under prediction of 50 percent, the world would then start to run out of short-run supplies. Only under these conditions would a rise of uranium above \$30/lb U_3O_8 be justified in order to bring additional resources to the 'market'. However, if one accepts the forecast of this analysis, then there is no reason other than 'market imper-

fections'-mildly speaking-for prices to behave differently.

It can also be concluded that the price jump of the late 1970s may have done great harm to hopeful investors who were misguided by a false price signal.At the same time unusual uranium discoveries were made providing greater certainty for future availability for a metal that was supposed to be near depletion. Consequently, users need not stockpile as much as before the price rise because future supplies are both larger and more certain than ever before. These are additional reasons why uranium prices will not rise above predicted levels excpet for standard increases in the cost of recovery.

In order to meet consumption requirements in the long run, new deposits could be opened up at the beginning of the 21st centruy, but obviously now before. It is in this long-run setting that Canada will eventually reap substantial benefits because the other short-run main suppliers of the world will have depleted their most valuable cheap resources. Canada will be one of the world's strongest uranium producers meeting rising domestic and external uranium consumption needs.

However, this optimistic outlook both in the long-run and in the secular sense has to be modified by the uncertain magnitude of the effects which technological changes will mean for the uranium producers. Justifiably

or not, Canada has missed the 'breeder boat' to offer Canadians the cheaper nuclear-electric energy they deserve. This event happened in 1973 when such policies could have been adopted to meet the stark-naked reality of the oil price garrotte. Hypothetically speaking, the CANDU-OC-THorium reactor could have been running in about 1993 as utilities in other countries are operating on fuel saving 'advanced fuel cycle' already today!

Nuclear fuel consumption in both long-run and secular periods will therefore be determined by the number of reactors and their fuel requirements and the degree in which plutonium and thorium breeders will have been built. The greater their number compared to conventional reactors the relatively lower will be future uranium requirements, the lower the price of uranium fuel and, hopefully, that of energy, and the longer the life-expectancy of the mineral resources which, when thorium is included,would stretch over centuries. Conversely, the greater the public aversion towards breeders and the later the thorium systems are on stream, the earlier will uranium resources be nearing exhaustion including the speculative resources, the faster will prices of uranium rise in the distant future and the more active - not to say prosperous - will be the uranium industry barring, of course, an early success of fusion technology.

However, very high uranium prices in the future would

have to trigger thorium substitution which would then deliver that cheaper energy because not only that fuel will be cheaper and, eventually, more plentiful than uranium but because thorium is more energy-efficient than other fuels, besides it does not deliver plutonium! Whether and when this substitution takes place will largely be determined by the constellation of uranium producers with the unintentional help by the anti-nuclear lobby, because most of the present uranium producers will most likely be the future suppliers of thorium, too. But as to nuclear fuel and its minerals as such, there is no real shortage. Shortages are created in imperfect markets and last only until a sufficient number of unrestraint mining competitors in a significant sector of the market can break the "UPEC" or the "uranium corner". To top it all, the number of competing countries is rising too!

NOTES

0 Steven A. Fetter and Kosta Tsipis,'Catatrophic Releases of Radioactivity', Scientific American, April 1981, p. 41-47, provides for effects of a grave reactor accident, a thermonuclear weapon and the detonation of a thermonuclear weapon on a reactor.

1 CRC, Handbook of Chemistry and Physics, 61st ed. 1980-1981, CRC Press, 1980, p. 8-44. Uranium: the scientific symbol is U; its atomic weight 239.029; specific gravity 18.95; melting point 1132.3°C; boiling point 3818°C. Thorium: scientific symbol: Th; atomic weight 232.0381; melting point 1750°C; boiling point about 4790°C.

2 Ibid.

3 Charles Weiner, "1932 - Moving into new physics", Physics Today, May 1972, p. 42.

4 Letter by Albert Einstein, Old Grove Road, Nassau Point, Peconic, Long Island, August 2nd, 1939, as rep. in Oak Ridge, The City that Changed the World, The Delmar Company (Knoxville, Tennessee, 1976), p. 4; as to James Chadwick, see Weiner, ibid. and Robert E. Jervis and J. S. Hewitt, "Nuclear Energy in Our Time", Our Energy Options Foreword by Arthur Porter, Chairman, Ontario Royal Commission on Electric Power Planning (Toronto, 1978) p. 108, as to Strassman, ibid.

5 The first two of these was the electro-magnetic separation process (Y-12), while the second was a gaseous diffusion process (in K-25) which is still used in the United States (Oak Ridge). Another method is based on the gaseous centrifuge. For a more detailed analysis of the economics of the nuclear fuel cycles with particular reference to the United States and covering uranium mining, milling, enrichment,demand and supply and prices see: S. Pasheer Ahmed, Nuclear Fuel and Energy Policy, Lexington Books Press, 1979; unavailable for this study!

6 Thorium 232 is changed into thorium 233 through an addition of a neutron; after 22.2 minutes that thorium decays to become Protactinium 233 which itself decays to become the fissile U 233 after 27 days; with a half-life of 158,000 years uranium 238 is transformed into uranium

239 through the addition of a neutron with a half-life of 22.5 minutes;when it decays it turns into Neptunium 239. After 2.35 days it decomposes into fissile Plutonium 239 with a half-life of 24,390 years. Asknowledgement of appreciation goes to Dr. D.E. Hallman, Department of Physics, Laurentian University for guidance through this very interesting field. For a discussion of the concepts of 'half-life' of an element see e.g. Robert E. Jervis and John S. Hewitt, loc. cit. (n.4 supra), p. 106-107.

7 Oak Ridge, ibid.,p. 24.

8 J.A.L. Robertson, Nuclear Energy in Canada: The CANDU System, Atomic Energy of Canada Limited, AECL 6328, October 1979, "Introduction".

9 Ibid., p. 7. Cf. Hugh C McIntyre, "Natural-Uranium Heavy-Water Reactors", Scientific American, Vol. 233, October 1975, No. 4 p. 17-27.

10 See no. 6 (supra).

11 Glenn T. Seaborg and Justin L. Bloom, "Fast Breeder Reactors", Scientific American, Vol. 233, No. 5, November 1970, p. 13-21; also see Floyd L. Culler, Jr. and William O. Harms, "Energy from breeder reactors", Physics Today, May 1972, p. 28-39. Both authors were reported at that time as working out of OakRidge; Culler was Deputy Director of the Oak Ridge National Laboratories and Harms Manager of the LMFBR in the same location.

12 M. Milgram, Things You've Always Wanted to Know About the Physics of Thorium-Fuelled CANDUS, Atomic Energy of Canada Limited, Chalk River, Ontario, August 1976, p. 1, AECL-5558. 100 neutrons absorbed by U 235 will result in 84 fissions; the same amount of neutrons will bring about 92 fissions in U 233.

13 M.F. Duret, Introducing Advanced Nuclear Fuel Cycles in Canada, Atomic Energy of Canada Limited, (Chalk River, Ontario, May 1978), AECL-6202, esp. p. 5; also see M.F. Duret and H. Hatton, Some Thorium Fuel Cycle Strategies, Atomic Energy of Canada Limited (Chalk River, February 1979), AECL-6414.

14 The breeder concept is as old as nuclear science, but it has required some time for the development of appropriate technologies. For an introduction to the following reactors and their technologies according to cooling

systems
1. Pressurized light-water-cooled,
2. Boiling light-water-cooled,
3. Heavy-water-cooled,
4. Gas-cooled,
5. Organic-cooled,
6. Liquid-metal-cooled, and
7. Liquid-fuel power; see
International Atomic Energy Agency, Nuclear Reactors Bibliographical Series, No. 2, 1960, p. 213-280; and Applied Science and Technology Index, up to most recent issues, H.W. Wilson Company, under: a) atomic power, b) nuclear reactors, and fuel, c) thorium, and d) uranium.

15 See G.T. Seaborg, loc. cit., p. 19; also Floyd L. Culler, loc. cit., p. 37.

16 Not mentioned are very small reactors decommissioned by 1970 such as Clementine EBR-1 and Lampre 1, all in the U.S.A., and BR-2 of the U.S.S.R. as happened in 1946, 1951, and 1961 respectively.

17 Georges A. Vendryes, "Superphénix, a Full-Scale Breeder Reactor", Scientific American, Vol. 236, No. 3, March 1977, p. 26-35.

18 Ibid., p. 34-35.

19 Ibid.

20 Ibid.; The small SNR 300 of Germany is likewise a multinational project.

21 James G. Busse, "Slow breeder makes its own fuel", Popular Science, April 1978, p. 89-91, 200, 202.

22 Charles T. Baroch and Charles J. Baroch, "Nuclear Energy Minerals and Their Utilization", Economics of the Mineral Industries, (ed.) William A. Vogely, a volume in the Seeley W. Mudd Series, American Institute of Mining, Metallurgy, and Petroleum Engineers, 3rd. (New York, 1976), p. 502; "Thorium was also used as nuclear fuel in a commercial electric generating plant at Ft. St. Vrain, Colo., and in experimental reactors". Robert Sisselman "Thorium Still Waiting for a Clear Energy Policy for the 1980s", E.& MJ., March 1980, p. 11.

23 Ref. n(s) 8, 12, and 13.

24 "A Comparison of the Economics of Nuclear Energy and Coal in Generating Electricity", *Nuclear Policy Review Background Papers*, Department of Energy, Mines and Resources, Ottawa, 1980, Report No. ER81-2 E.p. 29-48 esp. Tables 4 and 5, p. 38-39; also see Dr. W. Bennett Lewis, *Energy in the Future of Man: From Survival to Super-Living* ,Lecture at University of Calgary, October 7, 1975. Slide 1, p.5 where Lampton coal operations are compared to the Pickering Nuclear Plant. Unit energy cost stood at a ratio of 7.03/13.26(m $/kWh) as Pickering to Lampton.

25 A standard and simple forecast for the demand for energy in Canada is presented in op. cit., ER 81-2E, for the years 1980 to 2000: "Forecasts of Demand for Electricity: 1980 to 2000", ibid, p. 3-16. For 1990, expected required Base-Use Electrical Capacity would be 95,053 MWe, and 128,227 MWe in 2000 with sufficient supply capacity for 1990 (103,695) but insufficient planned capacity of 104,927 MWe (for 2000) estimated capacity deficiency of 23,300 MWe.

26 Dr. W.Bennett Lewis, *Abundant harnessed energy at low cost and low risk from nuclear fission* , Elizabeth Laird Memorial Lecture, University of Western Ontario, April 3 1974, esp. p. 11-12.

27 The optimistic cost at Pickering was 2.23 m (1949) $/kWh; ibid., Table 1, p. 10. See also J.A.L. Robertson, loc. cit., p. 8.

28 Source: Konrad B. Krauskopf, *Introduction to Geochemistry* 2nd ed., McGraw-Hill, International Series in the Earth and Planetary Sciences (New York, N.Y., 1979), p. 545.

29 *Encyclopedia of Science and Technology*, Vol. 13, rev.ed. 1977, McGraw-Hill (New York, N.Y., 1977), p. 629.

Thorium reserves and resources (ThO_2)

Country	Reserves (in metric tons)		
U.S.A.	136,090	Total U.S. resources	1,409,000
Australia	36,288	Probable and potential	2,391,000
Brazil	54,432		
Canada	208,656		
India	181,440	Major deposits contain	629,000
Malaysia	9,072	Probable and potential	1,996,000
Other market economies	54,432	Total from major deposits	2,625,000
Centrally planned economies	36,288		

as the resources from major deposits versus actual reserves of 136,080 metric tons or reserves are 5.2 percent of major deposits (or 3.6 of the sum total)

Source: Ref. Sisselman, ibid. (n. 22 supra) and based on USGS Circular 805; all figures have been computed into metric tons!

30 Encyclopedia of Science and Technology, ibid.

31 R.M. Williams, H.W. Little, W.A. Gow and R.M. Berry, Uranium and Thorium in Canada, Resources, Production and Potential, Mineral Resources Branch, Mineral Bulletin, HR 117, 1971, Department of Energy, Mines and Resources, Ottawa, 1971, p. 23.

32 Ibid.

33 Producers Shipment of Thorium recovered through the treatment of waste liquor from the uranium plants for the years 1959 to 1969. ThO_2 content in pounds and value of shipment in $Can:

Year	lbs	$Can
1959	47,447	105,676
1960	134,638	422,000
1961	103,282	392,000
1962	31,939	120,000
1963	77,539	464,000
1964	97,892	412,000
1965	46,339	189,000
1966	87,393	211,000
1967	117,383	215,000
1968	139,191	262,000
1969	29,014	55,000

Source: Statistics Canada, Miscellaneous Metal Mines, 1965, p. F27, and 1971, p. 19 (cat. 26-219).

34 New Thorium reserves: see no. 29 supra.

35 B. Lewis, ibid. (n. 26), p. 15; see also J.A.L. Robertson, loc. cit., p. 7.

36 Lewis, ibid.

37 Ibid.

38 Consumption (burn) requirements for the year 1980 were made in previous years and, in metric tons, amounted to:

For the Year 1980

Forecasts Made In

Year	Metric Tons	Apparent Source of Projection
1979	30,000	
1978	34,500	
1976	45,360	
1975	39,800	Australian Energy Commission
1974	76,500	
1973	73,800	
1972	59,000	
1971	61,700	
1970	49,500	
1969	65,300	USAEC
1968	78,900	ENEA/IAEA
1967	74,700	Canadian Nuclear Association
1966	58,950	

Note: All values have been taken from the Mining Annual Review, Annual eds. 1967-1979. In the 1980 edition, such forecasts have been deleted. It is also important to observe that these predictions were taken from different sources as indicated in the last column speaking for considerable inconsistencies in this series.

39 Cf. Walter C. Woodmansee, "Uranium", Mineral Facts and Problems, 1975, op. cit., p. 1189, Table 7 gives nuclear power reactor fuel as demanded for enrichment purposes and total industrial demand; e.g. in 1974, the former was 7,258 metric tons and the latter 8,165 metric tons (computed from short tons).

40 Ibid.

41 George White, Jr., "Uranium", Engineering and Mining Journal, March, 1981, p. 143.

42 Ibid., 1980, p. 195; and B.C.J. Lloyd, "Uranium", 'Nuclear Metals', M.A.R. 1980, p. 103.

43 B.C.J. Lloyd, "Uranium", 'Nuclear Metals', M.A.R. 1976, p. 92.

44 Mining output, eventually, is also affected by the uranium released from government stock piles from which, at least in the United States, a special 'Split Tails policy' has been implemented to modify the effects.

45 The writer apologizes to all Finnish friends for including their ethnic home country among the Eastern block nations. The reason for this distortion is simply that Finnish reactors are of U.S.S.R. origin and it has become customary to classify reactors into east and west not only by political lines of demarkation but also by origin of nuclear technologies!

46 Woodmansee, loc. cit., p. 1181.

47 Ibid.

48 Ibid.

49 Excluded are specifically: Bulgaria, Czechoslovakia, East Germany, Finland with two 'Russian' reactors (as commented in n. 45 supra), Hungary, Poland, Rumania, and,of course, the U.S.S.R.

50 This is a uranium-uranyl oxide; for further information on chemical aspects, see Woodmansee, loc. cit., p. 1180.

51 For instance, in 1967, the U.S.A. uranium consumption amounted to 907 metric tons while production stood at 8,657.4; Woodmansee, ibid., p. 1198, Table 13.

52 Technical Information Paper No. 2, p. 18. Note: for the year 1969, the Canadian source consulted did not list output of uranium.

53 Ibid.p. 17. Note erratum in heading 'U:08' which should read U308, in '000 lb.

54 <u>M.A.R. 1980</u>, p. 509; see Namibia under SECTION IV, infra.

55 See D.J. Lecraw, "The Uranium Cartel: An Interim Report", <u>Business Quarterly</u>, University of Western Ontario Press, Winter 1977, Vol. 42, No. 4, p. 76-77.

56 Ibid.

57 Ibid. Price tag:$Can. 101.4 million.

58 Ibid., p. 79.

59 Ibid., p. 78.

60 Ibid., p. 79, in reference to Gilchrist, White and Joskow

61 Cases in point are: OECD, Energy Prospects to 1985, Vol. 1, Report of the Secretary-General, Paris, 1974. In Canada, e.g. H. Hatton, Users Guide to the Computer Program FURST (FUture Reactor STrategies), Atomic Energy of Canada Limited, Chalk River, February 1981; also M.F. Duret, op. cit. (n. 13 supra); and J.H. Wright, Uranium Resources Consumption and 30-year Fuel Commitments For Canada and the World 1975-2025, Atomic Energy of Canada Limited, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba, May 1978.

62 Stephen Probyn and Michael Anthony, "The Cartel that Ottawa Built", Canadian Business, November 1977, p. 106.

63 This is an example of a manufacturer of reactors carrying uranium fuel inventories; cf. Probyn and Anthony, ibid., p. 104, and Lecraw, loc. cit., p. 82.

64 It is also clear that large stockpiles held by reactor manufacturers may mean competition to the producers of uranium. Consequently, fixed contracted prices were a choke on prices when resources were running short, as producers tried to force Westinghouse systematically against the wall; ibid.

65 For particulars, see E.E. Probyn and Anthony, loc. cit.; or LeCraw loc. cit.; or Ian Urquhart, "The cartel that blew sky-high", Maclean's Magazine, January 28, 1980, p. 8, 10-11.

66 LeCraw, ibid., p. 83 and Urquhart, ibid.

67 (a) Sept. 30, 1977, see: Department of Consumer and Corporate Affairs, Annual Report, Director of Investigation and Research, Combines Investigation Act, March 31, 1980, p. 50-51.
(b) LeCraw, ibid., p. 84, n. 36.

68 Statistics Canada, Exports by Commodities, monthly, (Cat. 65-004), Commodity Item 259-55.

Exports of Radioactive Ores and Concentrates

($ Can)	Exported To
June 1980, p. 76,	
5,243,000	United Kingdom
1,000	France
8,035,000	Japan
132,858,000	United States
June 1981, p. 78,	
10,720,000	United Kingdom
3,182,000	U.S.S.R.
2,022,000	South Korea
16,509,000	United States.

Cf: For alleged sales of enriched uranium by the U.S.S.R. to a U.S. utility, see Ch. 8 "Lead" p. 88.

69 Ibid.

70 Table A2.

71 Ref. R.E. Green and R.M. Williams, Nuclear Energy- One Road to Self-Sufficiency, Atomic Energy of Canada Limited, 1980, presented to the 94th Annual Congress of the Engineering Institute of Canada, April 23-25, 1980 Ministry of Energy, Mines and Resources, Ottawa, April 1980, AECL-6963; Table 1, p. 6 based on a publication of NEA/IAEA, December 1979.

72 Note: price is given in nominal (current) dollars.

73 RAR means: reasonably assured,
EAR means: estimated additional, and
SP means: speculative reserves.

74 Ibid., p. 10, and ref. p. 24(3): 1978 Assessment of Canada's Uranium Supply and Demand, Energy Mines and Resources (EMR), Canada, Report EP 79-3, June 1979. Also, see a version for public distribution: Energy Update, Energy Mines and Resources, April 1981, p. 39-43.

75 Engineering and Mining Journal, January 1981, p. 77.

76 Ibid.; and cf. E.& MJ., July 1981, p. 147: ore reserve 207,000 metric tons of U_3O_8.

77 Op. cit., January 1981, p. 77/78; reserves have been upgraded to 124,095 metric tons of U_3O_8; op. cit., July 1981, p. 147, with contracts signed to deliver 2,500 each to the U.S.A. and South Korea during the next eight and ten years respectively; ibid., Feburary, p. 159; and 2,858 metric tons between 1982 and 1996 to Sweden, op. cit., March, 1981, p. 208.

78 The Yeelirrie deposits are owned by Western Mining Ltd. (75%), Exxon Exploration Production Australia (15%) and Urangesellschaft Australia, Proprietary Co. (10%); the deposit is 5.6 miles long with an average width of 0.46 miles for a strike body of 2.6 square miles and 3 metres average thickness and 5.5(!) metres below surface. See also:"Western Mining nears completion of first - phase Yeelirrie development", Engineering and Mining Journal, May 1981, p. 59.

79 Op. cit., June 1981, p. 43. See also p. 236. Originally, Wyoming Minerals, a subsidiary of Westinghouse - a

manufacturer of reactors - sold its 51.03% stake in the Lake Way deposit. In exchange it will receive seven instalments of 50,000 lb of U_3O_8 if annual output reaches 8.2 million pounds, and a further 50,000 pounds should output reach 9.0 million pounds annually, ibid.

80 Op. cit., August 1981, p. 150.

81 Another two deposits have been located: the Maureen deposit near Georgetown, Northern Queensland, and Westmoreland deposit. The former is owned by Getty Mining Pty., Ltd. and contains 2,940 metric tons of uranium; it is only marginally viable given the mid-year 1981 market conditions; the latter involving a joint venture of four companies, contains 11,352 metric tons of U_3O_8 in six separate ore occurrences but would require a total deposit reserve of 15,000 metric tons to be commerically viable; ibid., p. 148.

82 Op. cit., January 1981, p. 49, p. 145.

83 Ibid., p. 47, 49; also ibid., July p. 144, which speaks of an enrichment plant planned by UEGA, Uranium Enrichment Group of Australia, consisting of BHP Ltd., Western Mining, Peko-Wallsend and CSR; ibid.

84 Op. cit., January 1981, p. 145-146, and May, 1981 p. 142; as to Sweden, see March 1981, p. 232.

85 Amok is a Dominion chartered active Canadian company of a group of companies owned by French companies and agencies: Cie. de Mokta (a subsidiary of Imetal, Paris, France) (25%), Pechiney Ugine Kuhlmann (25%), Cie. Française of de Minerais d'Uranium (20%) and Commissariat à l'Energie Atomique (30%); ref: Canadian Mines Handbook 1978/79, The Northern Miner Press Ltd., Toronto; however, in 1979 it agreed to sell 20% of its equity to the Saskatchewan Mining and Development Corporation; see EMR, "Canada" M.A.R., 1980, p. 345.

86 Eldorado had the intention to purchase the one-sixth of its interest in the Key Lake Property by borrowing 770 tons of uranium from the stockpile of the Federal government and to sell it at current world prices in 1978 whereby Eldor would have been liable to pay interest on the amount borrowed but to repay in kind from Key Lake operations. See R.M. Williams, "Uranium", Canadian Minerals Yearbook, 1978, Energy, Mines and Resources, Ottawa, Mineral Report 28, p. 486.

87 EMR, "Canada", M.A.R. 1981, p. 332. For a more informative assessment of Canada's uranium activities than that provided by B.C.J. Lloyd (ibid., p. 101), see ibid., p. 331-333, and, of course, R.M. Williams, loc. cit., p. 477-489.

88 M.A.R. 1981, p. 331.

89 Ibid.

90 Ibid., p. 332.

91 Canadian long-term outside commitments are reported to be 52,400 and inside ones 80,000 metric tons.

92 RTZ interests are at least 46.5 percent through its 41.35% direct holdings and through its 51.3% in Rio Algom (if not more) which has 10% interest in Rössing, though RTZ's voting rights are only 26%; other shareholders are: South African Industrial Development Corporation (47%), General Mining Union Corporation (2.3%) and Minatome of France (10%) accounting for a total of 77.12%. Engineering and Mining Journal, January 1981, p. 142; Life expectancy of the mine is 24 years.

93 M.A.R. 1981, p. 486.

94 Gold Fields S.A.

95 In neighbouring Botswana, very active prospecting for uranium is reported underway since the publication of magnetic surveys; M.A.R. 1980, p. 509.

96 M.A.R. 1981, ibid.

97 ABMS, Non-ferrous Metal Data, 1980, New York, N.Y., p. 133 provides a figure of 6,214 short tons of U_3O_8 which is equivalent to 5,637.3 metric tons and reflects the output of major mines.

98 M.A.R. 1981, p. 474.

99 IMMR, 1980, p. 89; i.e. U: 200-500 ppm, and Au: 7.23-15.48 ppm.

100 M.A.R. 1980, p. 493,"Breakdown of South African Gold and Uranium Production", (Major Mines) in 1979, notes.

101 IMMR, ibid.

102 The Mines are: Free State Geduld,
Free State Saaiplaas,
President Brand
President Steyn,
Welkom,
and Western Holdings.
Source: M.A.R., ibid., and IMMR, ibid.

103 IMMR, ibid.

104 Engineering and Mining Journal, January 1981, p. 77, and IMMR, ibid., p. 90-91.

105 Engineering and Mining Journal, July, 1981, p. 51.

106 Ibid.

107 Engineering and Mining Journal, January 1981, p. 77.

108 Engineering and Mining Journal, (hence forward E.& MJ.), May 1981, p. 182.

109 M.A.R. 1981, p. 474; and E & MJ, March 1981, p. 227.

110 M.A.R., ibid.

111 IMMR., 1980, p. 88.

112 M.A.R. 1981, p. 474.

113 E.& MJ., July 1981, p. 51, and M.A.R., ibid.

114 E. & MJ., ibid.

115 Ibid.

116 E. & MJ., August 1981, p. 145.

117 Gabon Government (25%), Cie. de Mokta (28.1%), COGEMA (15%) Minatome (13.1%), Cie. de Gestion d'Investissement (7.5%), Cie. des Mines de Huaron (3.8%); and operating at Mounana and Oklo at capacities of 1,500 and 1,400 metric tons of concentrates annually; M.A.R. 1980, p. 517.

118 Andrea M. Radigan, "Gabon", M.A.R. 1981, p. 495.

119 Ibid.

120 M.A.R. 1980, ibid.

121 This consortium consists of the Niger's government Office Nationale des Ressources Minières (Onarem (33%), Cogema, a subsidiary of France's CEA (27%), Compagnie Française des Minerais de l'Uranium (11.8%), Mokta (7.6%), Urangesellschaft (6.5%), and Agip Nucleare (6.5%); M.A.R. 1981, "Niger", p. 505.

122 Compagnie Minière d'Akouta (Cominak) consists of: Cogema (34%), Onarem (31%), the Overseas Uranium Resources Development Company of Japan (OURD(25%)) and Emprese Naçonal del Uranio of Spain (10%); ibid.

123 SMTT (Société Minière de Tassa N'Taghalgué is the company held by Onarem (50%) and Cogema (50%); ibid.

124 Cogema (35%), Conoco (35%), and Onarem (30%).

125 E.& MJ., January 1981, p. 77.

126 Cf. M.A.R. 1980, p. 530, and 1981, p. 507.

127 E.& MJ., ibid; according to M.A.R. the consortium is composed of Cogeman (37.5%), Onarem (37.5% and the Japanese OURD (25%).

128 This consortium consists of: Onarem (30%), Cogema (30%), the Nigerian Mining Corporation (16%), the Central Electricity Generating Board of the United Kingdom (12%) and German Saarberg-Interplan (12%).

129 Onarem (33%), Cogema (26%) and the Atomic Energy Organization of Iran (26%), a doubtful participant, and Agip Nucleare.Cf. M.A.R. 1980, p. 530; saw Canadian-based Pan Ocean Oil of Calgary, a subsidiary of Marathon Oil, involved at four deposits at the Algerian border.

130 M.A.R. 1981, p. 507.

131 Woodmansee, loc. cit., p. 1178, and Charles T. Baroch and Charles J. Baroch, loc. cit. (n. 22 supra.) p. 503-504.

132 Woodmansee, ibid., p. 1178, Table 1.

133 Ibid., Table 2.

134 Ibid., p. 1179, Table 3.

135 E.& MJ., March 1981, p. 47.

136 E.& MJ., January 1981, p. 77.

137 As to (1), ibid; and to (2) E & MJ, April 1981, p. 41; (3) E.& MJ., May 1981, p. 155.

138 E.& MJ., April 1981, p. 195.

139 Ibid., p. 52.

140 E.& MJ., January 1981, p. 72.

141 Ibid., p. 137.

142 Ibid., p. 136.

143 E.& MJ., April 1981, p. 41.

144 E.& MJ., May 1981, p. 11 and June, p. 167.

145 E.& MJ., May 1981, p. 148.

146 E.& MJ., June 1981, p. 178.

147 E.& MJ., July 1981, p. 131.

148 E.& MJ., January 1981, p. 77; but note the change recorded in the July issue, p. 39, 41.

149 Ibid., p. 41.

150 E.& MJ., January 1981, p. 77; cf: 'zero water discharge is target of Yugoslavia uranium project', E.& MJ., March 1981, p. 35, 39.

151 "Mexico steps up uranium exploration program", E.& MJ., April 1981, p. 31.

152 E.& MJ., January 1981, p. 226, 232. As to actual and potential uranium exploration activities as well as nuclear (power) investments the following cursory observations were made chiefly in the Mining Annual Review, 1981, with the location indicated either by the page number in the bracket or by respective other sources.

Brazil will be able to produce 1,000 metric tons of U_3O_8 at the Pocos de Caldas beneficiation plant by the year 1985 and 500 metric tons annually already in 1980. Reserves appear sufficient of feed 35 power reactors of the Angra II type during the full life of their services (p. 379).

For Chile two points can be made: in the north the Comision Chilena de Energia Nuclear is exploring for uranium while the Sociedad Minero Pudahel is able to produce 20 metric tons of uranium as a by-product at its Cascade copper mine. (p. 382).

In Columbia Camphagnia Colombia de Uranio (Coluranio) is exploring for uranium with Enusa of Spain, Minatome of France and the Power Reactor and Nuclear Fuel Development Corporation of Japan; three promising deposits have been found at Santander (Zapatoca), Cundinamarca (Quitamel) and in the Meta region. (p. 385).

Ecuador is thought to have uranium occurrences in the Andes to the south. (p. 386).

Paraguay has engaged two U.S. firms, Teton Exploration and Drilling Company and Anschutz to search and drill for uranium, although the potential is admittedly quite limited. $7 million have been spent on drilling. (p. 389).

China has extensive and widespread resources of uranium. This country will build its first nuclear power station in the densely populated areas of the south-east coast where coal is in short supply. (p. 435-436).

Japan is working on a plant to produce uranium hexafloride from uranium tetrafluoride aiming at an annual capacity of 200 tons to be completed by 1981. (p. 453).

Sri Lanka has confirmed the occurrence of traces of uranium in river and beach sands. (p. 455).

Thailand had invited for submission to explore for uranium in the north and north-east of the country. Apparently only Iron Mountain Mining has complied with this request. (p. 458).

In Mauritania Minatome and Cogema of France and the Tokyo Uranium Development Corporation are exploring for the metal in the area between Bir-Moghrein and Ain Ben Tilli which are connected by a road. (p. 515).

On the coastal areas of Morocco the Office Cherifien des Phosphates (OCP) started with the construction of uranium recovery units at Safi (1983); eventually similar units will be established at El Jorf Lastar and Nador. (p. 517).

In the Sudan two research tems, one from West Germany and the other from the University of Khartoum, have announced the occurrence of radioactive anomalies in the Nuba Mountains. (p. 521).

Zambia is likewise exploring for uranium. (p. 493).

Burundi is searching for uranium in the Butara-Bubanza-Masango region. (p. 493).

The Central African Republic has a known reserve of 18,000 metric tons of uranium but requires $500 million for its exploitation including the construction of transport facilities and access roads to produce 800 tons of uranium annually. (p. 496).

The Malagasy Republic is investigating a mineralization in the Ft. Dauphin region to the south of the island and near Tolagnaro in southern Madagascar; an agreement has been reached with Yugoslavia for the exploitation of such orebodies. (p. 499).

Mali has two uranium possibilities: Cogema of France is working on sites at Kéniébo, Taoudénit and Homborn while Japan's Power Reactor and Nuclear Fuels Development Corporation is exploring the area of Adrar des Iforas with occurrences at Kidal and Tessalit. (p. 509).

Guina has very promising uranium mineralizations with discussions under way for a joint venture involving possibly firms from such countries as Niger, France, West Germany, Romania, Switzerland, Yugoslavia, Morocco, the United States and Canada. (p. 512).

In Liberia, CLU Enterprises of Coast.States Gas of the United States is searching for uranium. (p. 514).

Algeria disposes of 28,000 metric tons of reserves in the famous Hoggar mountains. In 1979, the state-owned Sonarem mining company engaged an international consortium to develop the mining potential at Tingaouine with Cotecna Engineering of Switzerland in charge of the local infra-structure. A.G. McKee will build the processing plant while technical assistance will come from two Belgium companies, Union Minière and Traction & Electricité. M.A.R. 1980.(p. 540).

In Israel, the Energy Ministry has ordered the assessment of this country's phosphate reserves. So far, the reserves are about 275 million metric tons of phosphate with a potential uranium content of between about 27,000 and 55,000 metric tons of uranium, E.& MJ., June 1981. (p. 258).

Zimbabwe
Saarberg Interplan Uran GmbH, a German-government sponsored corporation,is surveying 34,000 km² for uranium in the Zambesi valley, while Union Carbide's Rhomet has been granted exclusive prospecting orders by Zimbabwe's government over five minerals including uranium in the Zambesi River and Lake Kariba areas covering 343,350 hectares, E.& MJ., Oct. 1981.(p. 190)

Philippines
In the Baguio Mining district in northern Luzon five areas have been recognized to contain potential uranium deposits. They are located in: Baa-Licuan in Abra Province, Batac and Burgos in Ilocos Norte, Aingay in La Union, and Ambalend River in Benguet. The Philippines Bureau of Mines is interested in obtaining fairly detailed surveys of these deposits, E.& MJ., October 1981. (p. 31).

153 Woodmansee, loc. cit., p. 1192, Table 10.

154 D.J. LeCraw, loc. cit., p. 77; calculated in tons of 2205 pounds each.

155 Ibid.

156 See E. & MJ., September and October 1981 under 'markets'.

157 See Ch. 1, p. 60.

158 See source of Table 9 in ref. to column (A) and (B) the latter for production.

159 Ibid., p. 133: 54,025 short tons was the output of uranium oxide; in metric tons this is equivalent to 49,011.48 metric tons which, after a proportionate adjustment in comparison to 1979 figures of the UN to those of ABMS provides for an estimated total output of 49,575 metric tons of U_3O_8.

160 E. & MJ., March 1981, p. 143.

APPENDIX A

Table A1
World Uranium Reserves by Main Resource Country
and Percentage Distribution
in Thousand of Metric Tons of U_3O_8

Country	'000 Metric Tons	%
United States	620	20.33
Canada	620	20.33
U.S.S.R.	500	16.39
South Africa	515	16.89
Namibia	90	2.95
Niger	160	5.25
France	65	2.13
Gabon	30	0.98
Australia	432	14.16
Others	18	0.59
World Total	3,050	100.00

Excluding China and other potential suppliers in Europe

Total	2,550	excluding U.S.S.R.

Source: Duncan R. Derry, A Concise Atlas of Geology and Mineral Deposits, Mining Journal Books, (London, 1980), p. 101.

Table A2

Recorded Uranium Reserves at Varying Prices for Selected Years During the 1970s

in '000 Metric Tons

Up to a Price/lb (U_3O_8) of	\$10	\$15	\$30	\$50
1970	761.4			
1973	961.8			
1975		1080.5	1393.8	
1977			1562.0	1799.0

Source: United Nations, <u>Statistical Yearbooks</u>, "Uranium" (U_3O_8), 1972, 1974, 1975, 1977, in ref. to publications by NEA/IAEA, ibid.

Table A3

Speculative Uranium Resources by Continent

Continent	Number of Countries	Speculative Resources (Million Metric Tons of U_3O_8)
Africa	51	1.52 - 4.72
America, North	3	2.48 - 4.25
America, South & Central	41	0.83 - 2.24
Asia and Far East[a)]	41	0.24 - 1.18
Australia and Oceania	18	2.36 - 3.54
Western Europe	22	0.35 - 1.53
Total	176	7.78 - 17.45[b)]
Eastern Europe, U.S.S.R. People's Republic of China	9	3.89 - 8.61[c)]
Estimated Total	185	11.67 - 26.06

Source: same as Table 9 (D), p. 11, Table 3, in ref. to source: NEA/IAEA, 1978, December.

a) Excluding People's Republic of China and the eastern part of the U.S.S.R.

b) A small portion of the potential given in these speculative resources may have been discovered between 1977 and 1979 without essentially changing the parameters of the table;

c) This estimated total potential of these countries may contain elements of RAR and EAR although these statistics were not available to NEA/IAEA

Note: the values here given differ from those of the sources in the sense that they have been expressed in U_3O_8 and not in tons of (U).

Table A4

Projection of Maximum Uranium Mining Capacity
For the Years 1980 to 2025
in Five-Year Intervals and
Thousand of Metric Tons of U_3O_8*)

Year	1980	1985	1990	1995	2000	2005	2010	2015	2020	2025
Country										
Australia	0.7	14.2	23.6	20.1	11.8	2.4	-	-	-	-
Canada	8.5	17.0	18.3	18.2	14.7	12.7	12.6	12.5	12.4	12.3
France	4.1	4.7	5.2	3.7	1.9	-	-	-	-	-
Namibia	4.8	5.9	5.9	5.4	5.4	-	-	-	-	-
Niger[1)]	5.1	12.4	14.2	12.0	6.5	4.1	-	-	-	-
South Africa	7.7	12.5	12.3	11.8	11.8	11.8	11.8	11.8	11.8	11.8
United States	23.5	37.0	48.1	55.1	60.9	55.1	48.0	30.0	14.5	-
Others[2)]	3.5	8.0	7.4	11.8	13.0	13.0	11.2	8.3	13.0	-
Subtotal	57.9	111.7	135.0	138.1	126.0	99.1	83.6	62.6	51.7	24.1
Phosphates[3)]	1.2	4.1	5.9	7.1	9.4	11.8	14.2	15.3	16.5	18.9
Grand Total	59.1	115.8	140.9	145.2	135.4	110.0	97.8	77.9	68.2	43.0

*) The original table from which these figures were extracted were given in tons of (U).

Markets and Prices

In February 1978 the Government of Ontario passed an Order in Council approving the purchase by Ontario Hydro of some 76,160 t U from Denison Mines Limited and Preston Mines Limited over the period 1980 to 2020. The Denison contract calls for delivery of 48,465 t U over the period 1980 to 2011 under a pricing formula that provides for a cost-related base price, plus one-half the difference between the base price and the world price, but no lower than the base. Ontario Hydro will also provide Denison's estimated $151 million (1975 dollars) expansion costs, interest free. The Preston contract calls for the delivery of 27,695 t U over the period 1984 to 2020, under a pricing formula which provides for a cost-related base price, plus one-third of the difference between the base price and the world price, but no lower than the base. Ontario Hydro will fund the total estimated $188 million (1975 dollars) cost of rehabilitating Preston's Stanleigh property, interest free.

The Ontario Hydro contracts were unprecedented in the world's uranium industry with respect to both the size of the sales and the length of the delivery periods. It was anticipated that they might have a significant influence on uranium prices in general and on Canadian export prices in particular. For example it was estimated* that Denison's initial deliveries could carry a base price in 1980 dollars from $101 to $109/

kilogram U (\$39 to \$42/lb U_3O_8), including the value for interest on the 'front-end' money. In Preston's case the comparable figure for deliveries in 1984 could be \$156/kg U (\$60/lb U_3O_8). A second significant indication of possible future uranium market prices was a February 1978 ruling by an arbitrator chosen by Rio Algom Limited and the Tennessee Valley Authority (TVA) that prices for 1979 deliveries under the Rio Algom-TVA contracts should be \$U.S. 118.09/kg (\$U.S. 45.42/lb U_3O_8). This price, which converts to about \$Cdn. 140/kg U (\$Can. 54/lb U_3O_8) under year-end exchange rates, was subsequently approved by Canada's Atomic Energy Control Board (AECB). Later, in December 1978, it was reported that prices for 1980 deliveries under the same contract were set by another arbitrator's ruling at \$U.S. 133.90/kg U (\$U.S. 51.50/lb U_3O_8), which converts to some \$Cdn. 159/kg U (\$Can. 61/lb U_3O_8).

Source: R.M. Williams, 'Uranium', Canadian Minerals Yearbook 1978, Energy Mines and Resources, Mineral Report 28, (Ottawa 1980), p. 485-486.